CANE SUGAR MANUFACTURE IN INDIA
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PUBLISHED BY
THE SUGAR TECHNOLOGISTS’ ASSOCIATION OF INDIA
21, COMMUNITY CENTRE, EAST OF KAILASH, NEW DELHI-110065 (INDIA)
FOREWORD

India has, in recent years emerged as the largest sugar cane and sugar producing country in the World, Thanks to the technological developments in sugar cane cultivation and sugar manufacture. The cane sugar industry of India spread over vast regions of the country occupies an important place in the economic and social life of the country in view of the wealth generated as well as the employment provided to lakhs of people in rural areas of the country. With about 436 sugar factories installed in both tropical and sub-tropical regions of the country it is the second largest agrobased industry and is poised for substantial growth in the years to come. The industry has the potential to produce a number of essential chemicals from its by products and generate extra power for supply to other industries or to state grids.

The modern sugar industry of India since it was established in the early thirties has witnessed vast technological changes over the past six decades, thanks to the research and development work carried out in the field of cane sugar manufacture in the country and also in the world sugar industry.

Subsequent growth of the industry has been accompanied by the technological advance in the production of raw material as well as the manufacture of sugar and the country is now in a position to export both raw & white sugar after meeting the internal demand of this sweetening agent. However technological progress is key to any further growth in the manufacturing sector and it is essential for the technologists engaged in the cane sugar manufacture to keep abreast of the developments taking place in different parts of the world in the field of technology of Sugar production.

Improving productivity and reducing the cost of production are important considerations underlying various modifications in the techniques of manufacture and the technologists engaged in the industry have to master the fundamental as well as practical aspects of the technology they are working with.
The long felt need for comprehensive book on the technology of plantation white sugar manufacture incorporating various aspects of plant operation will I hope be fulfilled by publication of this book on 'Cane Sugar Manufacture in India' by Shri D.P. Kulkarni a Sugar Technologist with wide and varied experience of cane sugar manufacture.

The Sugar Technologists' Association of India has so far brought out important publications dealing with scientific and technological aspects of cane sugar manufacture and it will not be out of place to expect this book to be useful to the Sugar Technologists in general and also to students prosecuting their post graduate studies in Sugar Technology. The efforts put in by Shri D.P. Kulkarni in collecting and compiling the vast technical information relating to various areas of cane sugar manufacture deserve to be commended and I believe that this publication will be well received by the Technologists of our Industry…..

SHIVAJIRAO G. PATIL
President S.T.A. India
PREFACE

Production of plantation white sugar or mill white sugar was first established in Java by end of the nineteenth century by carbonation process. Later on by beginning of the present century use of sulphur dioxide was introduced, which brought down the consumption of lime in cane juice clarification in the process of manufacture of white sugar from sugar cane. In India this process was introduced in the thirties, when a number of cane sugar mills were established following the protection granted to this industry. Since then considerable progress has been made in the past six decades in the field of Science and Technology of cane sugar manufacture and the techniques being adopted in modern sugar mills in India are fairly advanced. Remarkable strides have been made in different process operations in the recent past with a view to achieving improvements in productivity, efficiencies and quality of white sugar in the Indian Industry.

The present book aims at covering theoretical and practical aspects of each and every operation involved in the present process of white sugar manufacture from sugar cane and deals with recent techniques established in various cane sugar producing countries of the world. Moreover different technological options have also been discussed, as for instance, in juice extraction from cane apart from milling, diffusion has been described in details and in the section on cane juice clarification various processes tried out have been dealt with although sulphitation and carbonation processes have been discussed at great length.

In general it may be stated that almost all topics from harvesting of sugar cane to production and storage of sugar and molasses have been incorporated in this book and various operations connected with the entire process have been discussed from the technological point of view.

In the present context of the need to save bagasse in the process of sugar manufacture for production of paper, paper products or for generating extra power for other industries, energy conservation measures assume special significance and these have been thoroughly discussed in the chapters on evaporator and another chapter specially devoted to steam economy in process operation. Moreover the
by-product utilisation is also covered in one chapter in view of the fact that the Sugar Technologist has to be conversant with the technological aspects of by product based industries.

Every effort has been made to incorporate the latest developments in the field of cane sugar manufacture, that have significant bearing on improving productivity and quality of sugar in the this book. I am personally indebted to the President of Sugar Technologists' Association of India, Shri Shivajirao Patil for his initiative in getting this book published on behalf of the Association. I am also grateful to the Shri Vinay Kumar Hon. Secretary of the S.T.A. India and other office bearers of the Association for their efforts in bringing out this publication. The co-operation and assistance rendered by Prof. A.A. Zende Vasantdada Sugar Institute Manjri (B.K) Pune in effecting certain changes in the manuscript deserve special mention. I am thankful to Prof. Zende for the interest evinced by him in my work connected with bringing out this book.

It is hoped that this book will be found useful to the students of Sugar Technology Institutes as well as the technologists engaged in the sugar Industry.
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PROCEEDINGS OF ASSOCIATIONS AND JOURNALS:

I. Associations
1. International Society of Sugarcane Technologists'
   Abbreviation I.S.S.C.T.
2. Sugar Technologists' Association of India
   Sugar Tech. Assn. India
3. Deccan Sugar Technologists' Association India.
   Deccan Sugar Tech. Assn.
4. Australian Society of Sugarcane Technologists'
   Australian S.S.C. Tech.
5. Queensland Society of Sugarcane Technologists'
   Queensland S.S.C. Tech.

II. Journals
1. International Sugar Journal
   I.S.J.
2. Sugar Azucar
3. Sugar Journal
4. Sugar Technology Reviews
   (ix)
CLARIFICATION OF SOME TERMS USED

1. (i) Chlorophyll : Green colouring matter present in the leaves of plants.
   (ii) Photosynthesis : Process by which energy of sunlight is used by plants for converting CO₂ from atmosphere and H₂O into sugars.
   (iii) Maturity : State of full development, ready for use

3. (i) Bagasse : Residue of sugarcane after extracting juice from it.
   (ii) Cane preparation : Process of cutting sugarcane to fine pieces.
   (iii) Fibre : Thread like slender parts of sugar cane, insoluble in water.

4. (i) Clarification : Treatment of cane juice for removal of suspended and dissolved impurities.
   (ii) Clarifier : Equipment for settling treated cane juice, for decantation of clear juice and removal of settled portion, termed as mud.
   (iii) Filtercake : The insoluble material from treated juice retained on screen or cloth of filter.
   (iv) Clarified juice or Clear juice : The juice obtained after separation of precipitated impurities.

5. (i) Multiple effect evaporator : A set of bodies in which cane juice is concentrated with maximum use of vapours generated by boiling of juice.
   (ii) Vapour cell or pre-evaporator : A boiling vessel in which juice is boiled under pressure, the vapour thus generated being used for heating or boiling in process of manufacture, while the concentrated juice is led to multiple effect evaporator.
   (iii) Exhaust steam : Steam from primemover after generation of power.
   (iv) Live steam : Steam from boilers either at the boiler pressure employed for power generation or at reduced pressure for use in process.
   (v) Syrup : Concentrated clear juice from evaporator.
   (vi) Brix : Dissolved solids in sugar bearing liquid.
   (vii) Condensate : Hot water obtained on condensation of vapour or steam used for heating or boiling.
   (viii) Calandria : Part of a boiling vessel fitted with tubes or coils in which juices or syrups or thick liquors are heated by steam or vapour.
   (ix) Scale : (a) Deposit mostly consisting of inorganic salts on the inside of tubes in boilers or heating and evaporator vessels or pans.

(xi)
Coating of thin film of material outside the tubes of juice heaters, evaporator vessels or pans.

(x) Vacuum : State of reduced atmospheric pressure in a vessel.

(xi) Condenser : Apparatus in which vapours are condensed by cooling with water.

6. (i) Seed : Mass of fine sugar suspended in syrupy liquid boiled in vacuum pans with sugar-bearing liquids.

(ii) Massecuite : Mass of sugar crystals surrounded by sugar containing liquor, obtained in vacuum pans.

(iii) Molasses : Mother liquor separated from sugar crystals contained in massecuite.

(iv) Heavy Molasses : Mother liquor obtained by centrifugal separation of sugar crystals from massecuite with little or no use of water.

(v) Light molasses : Mother liquor obtained during centrifugal operation with application of water, after separation of heavy molasses from massecuite.

(vi) Pan : Apparatus in which syrup or molasses are boiled so as to obtain sugar crystals of the desired size.

(vii) Molasses conditioning : Dilution of molasses from different massecuite to about 70° Bx followed by heating to 70°C.

(viii) Final molasses : Mother liquor obtained from the last stage of boiling from which sugar can no longer be recovered economically in the process of Sugar manufacture.

7. Crystalliser : Apparatus in which the massecuite from pan is discharged, equipped with stirring mechanism.

8. (i) Centrifugal : Machine for separation of sugar crystals from mother liquor by rotary motion and centrifugal force.

(ii) Superheated water : Water heated under pressure above its boiling point.

(iii) Spinning or purging : Separation of Sugar crystals in centrifugal machines.

(iv) Pug mill : Vessel, provided with stirrer, on top of centrifugal machines receiving massecuite or magma, which feeds the centrifugal machine.

(v) Grass hopper : Sugar conveyor with shaking motion.

(vi) Grader : Apparatus with set of screens subjected to vibrations for classifying final sugar into different size grains.

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1. SUGAR AND SUGARCANE

1. HISTORICAL

1.1. Sugarcane the kindly fruit of the earth, known to India since times immemorial is one of the most abundantly grown crops on earth, forming major source of crystal sugar and other sweetening agents for human consumption. Sugarcane i.e. 'Saccharum officinarum' is said to be in existence in Papua New Guinea, for over 12,000 years which thus is considered its original habitat and from where it spread to south east Asia and India in the course of few thousand years. The earliest record of sugar cane in world literature is found in 'Atharva Ved' one of the sacred Hindu Scriptures supposed to have been composed 1000-5000 years before the Christian Era while the first reference to 'sugar' is observed in an Ancient Indian treatise 'Pratimoksha' dealing with Buddhists' code of conduct written two thousand six hundred years back. The ancient Sanskrit literature produced thereafter is replete with references to sugarcane and production of sugar therefrom. In the legendary paradise created by sage Vishvamitra for the King Trishanku, sugarcane was one of the plants grown, which was later thrown down on earth as gift to mortals. Charak and Sushrut Samhitas the standard works on the Hindu science of medicine 'Ayurved' dating back to 2nd or 3rd Century B.C. mention besides sugarcane and its product sugar, the medicinal usage of sugar. References to sugar in Arthshastra of 'Kautilya' the mentor and minister of Emperor Chandragupta, the founder of Maurya Dynasty (300 B.C.) show the importance of sugar as commodity of general consumption liable for taxation. India is thus home of sugar where the cultivation of sugarcane and the science of manufacturing sugar were developed in ancient times and from where it spread to different parts of the world.¹

In middle ages sugar was an important commodity of thriving trade in the subcontinent which was exported to western countries as an article of luxury, by European traders and the legendary East India Company established in 1600 A.D., until the establishment of colonial rule by the Europeans in different parts of the world which incidently coincided with the dawn of industrial revolution.

1.2. The modern vacuum pan cane sugar industry in India owes its origin to the first enterprises of Englishmen who at the beginning of the twentieth century set up half a dozen sugar factories in U.P. Another important landmark in the historical development of the Indian Industry was the release of new varieties of sugarcane as a result of the pioneering breeding research work of the sugarcane breeding institute established in 1912. However no perceptible progress in the sugar production was discernible until 1932 when the Government of India acting on the report of the Tariff Board imposed high protective tariff to encourage indigenous industry. In consequence of this, the industry received a
fillip and the number of factories rose to 132 before the commencement of second world war, mostly in the subtropical belt of the country. Till then from the time alien rule was established in India huge quantities of sugar were imported from other countries, which had reached peak in 1930 but dwindled thereafter to insignificant level by 1937 since by that time India had attained self sufficiency in sugar production. The decade before second world war thus saw the renaissance of this vital industrial activity. However real spurt of the activities in the various areas of development of this industry had to await the dawn of Independence.

1.3. Growth of Sugar Industry after 1950—Sugar production was stagnant at around 1.0-1.3 million tonnes per annum prior to independence. Post independence era saw the launching of five year plans for economic development and for meeting the growing internal demand of sugar, the sugar manufacturing capacities were increased in each plan period, by establishing new sugar mills, mostly in the tropical belt, where yields of sugar cane and sugar are higher than those in the subtropical region of our country. The number of factories has gone up from 136 in 1950 to 396 in the past four decades, with a potential for producing about 13.0 million tonnes of sugar per year. In table I are presented figures for sugar factories in operation and the production of sugar by vacuum pan factories in different years in the past.

2. PRESENT STATUS OF THE WORLD CANE SUGAR INDUSTRY

2.1. The total crystal sugar manufactured in the world is over 110 million tonnes per annum, out of which the cane sugar accounts for 60-65% of the production, the remaining being the share of the beet sugar industry located mostly in Europe, U.S.A. and some cold regions of the globe. The cane sugar industry is widely dispersed in different regions of the world like India, Australia, South America, Africa, U.S.A., and many parts of Asia, enjoying tropical warm climate (Table 2). Based on the types of sugar produced the cane sugar factories can be classified into four categories as under—

(i) Raw Sugar—In many sugar producing areas raw sugar of 98-99 purity is produced from cane, which is sent to refineries or exported. This sugar being unsuitable for direct consumption is later converted into refined sugar of very high purity.

(ii) Refined Sugar—White and sparkling in appearance the refined sugar is of 99.9 purity and is used directly for human consumption, besides a small proportion for pharmaceutical and chemical industries. A substantial portion of the total sugar produced for direct human consumption is manufactured in refineries with a normal capacity range of 200—2000 t. per day. These are mostly situated in urban areas which are major consuming centres.

(iii) Raw Sugar Factories-cum refineries—In these factories producing raw sugar from sugar cane, small refining units are installed for processing the raw sugar and manufacture of refined sugar. The refinery can operate throughout the year even though the raw sugar production is confined to the crushing campaign restricted to dry periods of the year.
(iv) **Plantation white sugar factories**—In India and some of the developing countries white sugar is manufactured from cane for direct consumption employing more complicated techniques in clarification of juice and also in crystallisation of sugar. The sugar produced is of 99.8% purity and contains slightly higher amount of impurities than the refined sugar. These plants can also produce raw sugar either for export or supply to refineries.

With the exception of raw sugar refineries, the cane sugar factories are necessarily located in cane growing tracts usually away from urban areas. The capacities of cane sugar factories expressed in terms of tonnes cane processed per day vary widely from 1000 to 20,000 or even more, depending on the availability of raw material as also the market conditions.

The crystal sugar constitutes an important article of food serving as major sweetening agent. The per capita consumption of sugar is more or less related to the standard of living as shown by the table 3 on per capita sugar consumption in different countries of the world.

2.2. Indian cane sugar industry scenario—In India sugar cane is cultivated extensively in vast areas of the subtropical and tropical belts of the country. Out of the sugar cane produced substantial portion (40-50%) is diverted to Gur and Khandsari factories while (40-45%) is utilised for production of sugar by vacuum boiling process, the remaining 8-12% being consumed for chewing or seed.

Sugarcane is thus processed in India for producing three types of sweetening agents viz., Gur, Khandsari Sugar and Vacuum pan crystal white sugar, for direct consumption, as well as for manufacture of sweets by indigenous methods. Gur manufacture which is essentially a cottage industry involves—

(a) extraction of juice in small three roller crusher.

(b) solidification by evaporating water in open pans.

(c) In the open pan process of Khandsari Sugar manufacture practised in hundreds of small scale units, the juice is extracted in five or six rollers, clarified by sulphitation and evaporated in open pans on furnaces, to yield concentrated mass which on curing gives crystal sugar.

3. **SUGARCANE**

3.1. Sugarcane, with its high fibre and carbohydrate content constitutes an important renewable source of energy. During its long growth period of 10 to 16 months this plant converts good amount of solar energy into sugar and cellulose and is considered to be one of the most energy efficient crops in that the energy provided by the biomass of fully grown cane is four times the energy input during the crop cultivation. Sugarcane sets are planted in soil and the plant develops growth in the course of its life cycle, during which it converts water and CO₂ from atmosphere into carbohydrates in the presence of sunshine, a phenomenon termed as photosynthesis.
3.2. In the growth phase of the plant, sugar accumulation occurs more in the lower portion of the stalk, progressively decreasing from bottom to top joints but in a fully mature cane this disparity is practically absent or negligible. Within the stalk the internodes are richer in sugar while the fibre content is higher in the nodes as shown by the earlier studies on variation in composition of these portions. This difference in composition accounts for two observations:

(a) Cane with short internodes will give high fibre and lower sugar content.

(b) The juice expressed in the last mill under heavy pressure is of lower purity than the first or second mill.

Sugar cane plant standing in the field consists of three principal portions viz.

(a) The leaves, the tops, and

(b) The stalk.

The tops and leaves contain very low sugars but are rich in salts in solution as well as water. The sugarcane stalks delivered to the factories have to be free from the tops and roots and as such during harvesting, care is taken to remove them so that the sugar rich portions of the plant are processed. The principal components of the cane stalks to be processed for commercial sugar production, are

(i) around 70-75% water.

(ii) 12 to 15% water insoluble fibre, and

(iii) sucrose and other carbohydrates.

Besides these the composition of juice extracted from cane is marked by varying amounts of mineral salts and organic compounds. The composition of sugarcane is conditioned by the variety of cane, soils and agricultural factors in addition to the climate during the different phases of growth of the plant.

At the end of its growth period, the sugarcane crop reaches maturity, during dry weather, marked by highest sugar build up, when it is considered to be suitable for harvesting. If allowed to stand in the field after its maturity phase, it starts deteriorating in the sense that sucrose gets decomposed with the formation of nonsucrose compounds and cellulose. The overmature cane will thus build up higher fibre with reduced sugar content and it is absolutely essential for the processing factories to harvest the cane after it attains full maturity.

3.3. Sugars in general are known as carbohydrates being formed of carbon, hydrogen and oxygen. Simple sugars like glucose, fructose etc. are monosaccharides which cannot be further decomposed into simple carbohydrates by either acids or enzymes. When composed of five carbon atoms these carbohydrates like arabinose are termed as pentoses. Likewise sugars like glucose, fructose containing six carbon atoms are known as hexoses. Monosaccharides condense together to form disaccharides or even trisaccharides containing two or three monosaccharides. Sucrose, maltose and lactose belong to the category of disaccharide which under influence of acid or enzyme form simple
monosaccharides. Sucrose is the condensation product of glucose and levulose or fructose, the first being an aldehyde while the latter contains ketone group. Several polysaccharides produced by condensation of monosaccharides, are present in sugarcane like gums, dextran, starch, cellulose, which when reacted by acids or enzymes are converted to monosaccharides.

3.4. The major components of sugarcane, besides water are as under

3.4.1. Sugars

(a) Sucrose—Commonly known as sugar in the popular parlance, this is the major constituent of sugarcane and belongs to the family of carbohydrates formed out of 'C', 'H', and 'O'. The chemical formula for sucrose is \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \).

Structure—Structurally the sucrose is represented as \( \alpha\text{D Glucopyranosyl } \beta\text{D fructofuranoside} \). The configuration of sucrose and its two main monosaccharides is as under—
In its pure form this sugar is crystalline in nature. Sucrose content in fully mature cane ranges from 12-15%. Under conditions of low pH or under influence of certain enzymes like invertase sucrose is hydrolysed into two monosaccharides viz. glucose and levulose in equimolecular proportions according to equation:

\[
C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6
\]

This reaction is commonly known as inversion and the resulting solution as invert sugar.

Following are some physical and chemical properties of sucrose which is basically a disaccharide:

(i) Molecular weight 342.3.

(ii) Density of 26% solution at 20°C 1.108175.

(iii) Sucrose melting point is 188°C but it decomposes on melting.

(iv) Sucrose is soluble in water and ethanol and the saturated solution in water at 20°C contains 67.09% sucrose by weight & in ethanol at 20°C, 0.9% by weight.

(v) Sucrose is optically active and specific rotation of normal solution (26 gms 100ml) is +66.53 at 20°C but on inversion the solution has optical rotation of -39.7 at 20°C.

(of) Crystals of sucrose are monoclinic prisms with density of 1.588.

(a) Chemical—

(i) When heated to 200°C the sucrose loses water forming brown coloured compound known as caramel.

(ii) Sucrose on treatment with concentrated nitric acid is transformed into oxalic acid

\[
C_{12}H_{22}O_{11} + 9O_2 \rightarrow 6 (HOOC - COOH) + 5H_2O
\]

(iii) When concentrated sulphuric acid is added to it sucrose is charred with evolution of CO₂ and SO₂.

(iv) Sucrose reacts with hydroxides of calcium, barium and strontium to form sucrates

\[
C_{12}H_{22}O_{11} + 3Ca (OH)_2 \rightarrow C_{12}H_{22}O_{11} 3CaO + 3H_2O
\]

Sucrates or saccharates are decomposed by passing CO₂ through the aqueous suspension.

(b) Glucose—Also known as dextrose, this monosaccharide has a chemical formula \( C_6H_{12}O_6 \). The two major monosaccharides viz. glucose and fructose or levulose are present in higher amount in the immature cane but their percentage decreases as cane reaches maturity. In a sugarcane plant the presence of glucose and levulose is more marked in the cane tops man in the middle portion of stalk. Glucose is sensitive to alkaline condition and heat undergoing decomposition under action of heat and alkali to form coloured compounds. It is less soluble in water than sucrose. The major physical properties of glucose are
(i) Empirical formula $C_6H_{12}O_6$

(ii) Molecular weight 180.2.

(iii) Anhydrous glucose crystals are rhombic, with density of 1.544 and melting point of 146°C.

(iv) Glucose is soluble in water and ethanol the solubility at 30°C in water being 57.6% in a saturated solution.

(v) Glucose is dextrorotatory and in solution specific rotation changes on standing - a phenomenon known as mutarotation. On reaching equilibrium the glucose solution has a specific rotation of 52.7° at 20°C.

(c) Levulose—Levulose or fructose a levorotatory monosaccharide is present along with glucose in the growing partitions and tops of cane more than in the main stalks. The empirical formula of fructose is the same as for glucose i.e. $C_6H_{12}O_6$. Out of the two monosaccharides i.e. glucose and fructose, the proportion of fructose is less than that of the former. It is highly soluble in water but less soluble in ethanol and at 30°C the saturated solution of fructose contains 81.54% of this sugar. The physical properties are as under:

(i) Molecular weight 180.2.

(ii) Specific rotation -92.4 at equilibrium.

(iii) Crystal structure-orthorhombic with density of 1.598 and melting point of 105°C.

Fructose has a ketonic group in its structure unlike glucose which has aldehyde group. Being highly susceptible to heat and alkaline conditions it gets decomposed under these conditions. Like glucose fructose reduces cupric salts.

3.4.2. Starch—Starch is formed by condensation of glucose molecules and is present in cane juice in small amounts the percentage depending on the cane varieties as also soil and other natural conditions. Varieties like NCO 310 contain high amount of starch (300 mgms/1) in juice and in South Africa sugar cane of any variety is reported to contain high starch. The starches which are polymers of glucose consist of a chain polymer to the extent of 20% known as amylose and remaining about 80% branched polymer, amylpectin. Starch is insoluble in water but its fine granules are extracted in mills and during heating of juice it gets partially dispersed in juice. During clarification it is only partially removed and if the original starch content in juice is high (250-350 ppm) serious problems are encountered at both clarification and crystallisation since the sucrose crystallisation is hampered by the presence of starch. The amylose fraction of starch exerts depressing effect on the filtration rate.

Presence of starch beyond a certain concentration (50-100 p.p.m) in raw juice creates problems in the process operation and special treatment of juice is resorted to for decomposition of starch. Starch is soluble in hot water and unless its level is significantly brought down in juice the filtration and sucrose crystallisation are adversely affected. Consequently the factories producing crystal sugar prefer to process varieties low in starch content In case however it is unavoidable to deal with cane of high starch content,
it is eliminated by adopting special technique of juice clarification or use of bacterial enzyme.

3.4.3. Fibre—This water insoluble portion of the sugar cane plant is present in abundance and forms important component of sugarcane along with sucrose. The principal constituent of the cane fibre is cellulose and the complex fibrous structure of the plant is bound together by lignin, pectin and hemicelluloses. The cellulose is composed of chain of glucose molecules held together closely with varying degrees of polymerisation.

3.4.4. Other organic polymers—Gums in sugarcane composed of six different monosaccharides, are soluble in water but insoluble in acidified ethyl alcohol. Though removed in the process to some extent they persist till the final stage and are present in molasses and to some extent in sugars.

Another polymer of significance is dextran consisting of glucose molecules and is produced by the bacteria Leuconostoc mesenteroides, which is highly dextrorotatory with specific rotation of +199 at 20°C. Frozen cane or harvested cane left over in field or factory without processing for long period are often found to contain high amount of dextran which unless eliminated in the first stage of processing creates difficulties at crystallisation, contributing to high loss of sugar in manufacture. In milling, dextran formation is observed in stagnant pockets of cold juice and special bactericides have to be sprayed to check the growth of the Leuconostoc bacteria. In the process operation dextran can be decomposed by use of enzyme known as dextranase.

3.4.5. Organic acids and nitrogenous compounds—Cane juice is acidic in nature with pH of 5.0-5.5. Stale, immature or frozen cane yields low pH juice with high amount of free acids. Out of the different organic acids aconitic acid claims the major share in the juice from normal cane. Deterioration of cane after harvest or due to natural causes results in generation of acetic acid, lactic acids etc.

A number of amino acids and amides have been identified in cane juices like aspartic acid, glutamic acid, alanine, valine etc. the first one i.e. asparagine being the most dominant amino compound. The proteins in cane are extracted to maximum extent in the last one or two mills where cane is squeezed under high pressure with application of hot imbibition water. These are mostly eliminated in clarification. However the amino acids are unaffected by the treatment in clarification and accumulate in final molasses.

3.4.6. Colour forming compounds and pigments—Natural pigments like chlorophyll, xanthophyll and carotene present in the cane plant are extracted in milling but are eliminated in juice clarification and subsequent boiling operations. However organic compounds like polyphenals, Flavonoids which give rise to coloured products in the process of manufacture resist elimination during clarification. Presence of Polyphenols is more marked in the tops and immature portion of sugarcane and they give rise to coloured compounds with ferric ions and are found to create problems in settling of juice when the percentage of phenolic compounds exceeds certain limits. To maintain low level of phenols it is essential to top the canes properly before in the fields at the time of harvesting.

3.4.7. Inorganic compounds—Sugar cane plant during the period of growth absorbs various
minerals from the soils, which are partly dissolved in water and to some extent are present as organic compounds. Prominent among them are anions phosphates, sulphate, chlorides and cations like silica, Iron aluminium, calcium, magnesium, potassium and sodium. Maximum inorganic matter is found in juices from immature cane tops gradually decreasing to the lower portion of the plant. This makes it all the more necessary to avoid milling of cane tops. These salts are extracted in juice and only partially removed by the normal clarification methods followed in factories as for instance in juice rich in phosphate after clarification the phosphate level is brought down. The potassium which forms major constituent of the mineral matter of the cane juice persists throughout the process getting accumulated in final molasses. The anion chloride also remains unaffected by the clarification or juice concentration and is found in final molasses.

The mineral matter content in cane juice depends primarily on the nature of soil as well as manurial practices and high concentration of minerals in juice is responsible for high loss of sugar in molasses.

3.4.8. Lipids—Sugarcane outer surfaces are coated with waxy lipids which are discernible on the rind of the cane stalk as whitish coating. The fatty lipids and wax are extracted in milling to the extent of nearly 40-50% and are eliminated in the filtermud during clarification. These lipids consist of a mixture of alcohols, free acids and esters. Crude wax extracted from filtercake contains, resins and soft portion or oils apart from hard wax. The crude wax content of dry filtercake usually varies from 8-12%. Wax extraction from the filtermud separated in clarification is being commercially operated in some countries in view of the potential offered by this product for use in other industries where other vegetable waxes are being used.

4. PROCESS OF MANUFACTURE OF SUGAR FROM SUGARCANE BRIEF OUTLINE

4.1. The cane received in the factory yard is fed to the carrier by mechanical unloader from trucks and trailers while the cane carts are manually emptied. The cane is passed through preparatory devices like knives, for fine cutting before being subjected to crushing in a milling tandem comprising 4 to 6 three roller mills. Fine preparation, with its impact on final extraction, is receiving special attention and shredders and particularly the fibrizers are gaining popularity. The mills are of modern design, being equipped with turbine drive, special feeding devices, efficient compound imbibition system etc.

4.2.1. White sugar by sulphitation process—The raw juice after being heated to 65-75°C is treated with phosphoric acid, sulphur dioxide and dilute lime solution for removal of impurities in suspension in a continuously working apparatus. The sulphur dioxide is generated by combustion of sulphur, while lime is either produced in Kiln from limestone or bought as such and stored in a separate house. The treated juice on boiling is fed to continuous clarifier from which the clear juice is decanted while the settled impurities known as mud are sent to continuous vacuum filter for removal of unwanted stuff. The clear juice with about 73-75% water is concentrated in a multiple effect evaporator under vacuum to yield syrup with about 37-43% water content. The syrup is again treated with sulphur dioxide before being sent to the pan station for crystallisation
of sugar. It is at the vacuum pan boiling stage that the sugar crystals appear. The crystal containing mass from the pan is dropped in crystallisers and subsequently centrifuged in centrifugal machines for isolating sugar crystals from mother liquor, which again is sent to pan for boiling and recrystallisation. Three stages of recrystallisation are adopted to ensure maximum recovery of sugar in crystal form. The final mother liquor referred to as final molasses is sent out of the factory as waste being unsuitable for recovery of sugar under commercial conditions from economic point of view.

Under conditions of Deccan Sugarcane processing yields—

(a) 27-30% bagasse containing around 46% fibre.
(b) 3.5% filtercake containing 30% dry matter and,
(c) about 4% final molasses containing 80% dry matter besides about 10.5 to 12% crystal sugar which is the principal product of manufacture.

4.2.2. Corbonation process—In factories producing white sugar by corbonation process of clarification, the raw juice heated to 55°C is treated with heavy dose of lime and CO$_2$. Separation of precipitates of CaCO$_3$ accompanied by the impurities from raw juice is effected in filters in two stages as also reaction with CO$_2$. The resulting alkaline clear juice after second filtration at pH of 8-8.5 is neutralised by treatment with sulphurdioxide. Different methods of clarification by lime and CO$_2$ treatment have been developed and are being practised commercially, such as middle juice clarification, phosphatation of alkaline juice etc. but essentially the principles underlying all these are identical.

In other respects the process operation is the same as practiced in sulphitation plants.

4.2.3. Raw sugar—In raw sugar manufacture the raw juice after addition of required dose of phosphate is heated to 70°C and treated with lime to a pH of 7.2-7.4. Further heating to 100°C followed by separation of clear juice by decantation in clarifier and subsequent processing steps are the same as followed in white sugar manufacture with the exception of elimination of melting of low grade sugar and washing of final product of manufacture. The sugar produced is of 98.5-98.8 polarisation and the crystals are surrounded by thin film of molasses presenting brownish appearance.

5. PLACE OF SUGAR IN HUMAN LIFE

5.1. Sucrose commonly known as sugar has an important place in human life not only as an article of food but also as an ingradient of various medicinal preparations and even as a raw material for some products of every day use. Sugar is thus consumed not only as sweetening agent in the human diet but also in pharmaceutical, food and other industries.

5.2. Sugar which is formed by photosynthesis in plants from sun's energy is a natural food for all living beings. In the human system, when taken orally, the sugar is attacked in the stomach by hydrochloric acid of the gastric juices and converted into glucose and levulose. In the small intestines these sugars are absorbed through the intestinal capillaries in the portal vein whence they are carried to liver and stored there. Sugar above a certain level in blood is converted into a polysaccharide known as glycogen to be
decomposed into simple dextrose and used whenever sugar level of blood falls below certain limit. Energy required for any activity of the brain or muscles is supplied by dextrose getting oxidised into CO$_2$ and H$_2$O. The sugar taken orally raises the blood sugar level in the human system within five minutes\(^5\). Sugar thus serves as a source of quick supply of energy to the body for any physical or mental activity.

5.3. Good amount of work has been carried out on the relative sweetness of sugar and some edible compounds. The relative sweetness is a function of concentration, temperature and pH. The mixtures of different components when evaluated in terms of sweetness present a complex picture in that the sweetness values are not necessarily additive. Relative sweetness values assigned to different sugars are as under\(^6\):

(i) Sucrose—1  
(ii) Glucose—0.7  
(iii) Fructose—1.1  
(iv) Invert sugar—0.9

(v) Xylose—0.7  
(vi) Maltose—0.4  
(vii) Lactose—0.4  
(viii) Galactose—0.6

5.4. Food products—In view of its quick absorption in human system, place of sugar in every day diet in various forms is without any parallel. It enhances the natural flavour of fruits and is used in fruit canning in a big way. Sugar serves as a good preservative for edible products which can keep well in concentrated sugar solution for quite some time without deterioration. Fruit preservation and canning is a big industry in advanced countries of the world. It is widely used in beverages in tea, coffee etc. in most of the countries and forms the principal raw material base for candy as well as confectionery industries.

5.5. Pharmaceutical and other industries—Sugar syrups i.e. concentrated sugar solution containing one of more medicinal ingredients are quite common. In smaller amounts sugar is used for coating for medicinal tablets or pills which are bitter in test, so as to make them palatable. Apart from these, following products can be manufactured with sugar as base\(^7\).

(a) Sorbitol used in diabetic food and for producing ascorbic acid.

(b) Lactic acid which forms an important chemical intermediate in food, pharmaceutical and leather industry is produced by action of lime on sucrose at high temperature 240°C.

(c) Oxalic acid is manufactured by oxidation of sucrose by nitric add.

(d) Sucrose octaacetate produced by the action of acetic anhydride and sodium acetate is used as adhesive, plasticiser etc.

(e) Nonionic surfactants are manufactured from sucrose and fatty acids. These surfactants with good wetting properties are widely used in food, pharmaceutical industries and cosmetics. As detergents these surfactants have gained wide acceptance in the market. Being biodegradable these surfactants are preferred to the propylene, benzene based surfactants. The sugar fatty acid based sucrose surfactants are produced commercially in U.K., Japan, France etc\(^7\).
REFERENCES


4. 'Wax and Fatty Byproducts from Sugarcane' Sugar Research Foundation Inc. New York 1947 p. 10.


<table>
<thead>
<tr>
<th><strong>SI No.</strong></th>
<th><strong>Year</strong></th>
<th><strong>No of Factories</strong></th>
<th><strong>Cane crushed (in lakh tonnes)</strong></th>
<th><strong>Sugar produced (in lakh tonnes)</strong></th>
<th><strong>Recovery (%)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1930-31</td>
<td>29</td>
<td>13.39</td>
<td>1.20</td>
<td>8.96</td>
</tr>
<tr>
<td>2</td>
<td>1940-41</td>
<td>148</td>
<td>114.92</td>
<td>11.13</td>
<td>9.70</td>
</tr>
<tr>
<td>3</td>
<td>1950-51</td>
<td>139</td>
<td>113.48</td>
<td>11.00</td>
<td>9.99</td>
</tr>
<tr>
<td>4</td>
<td>1956-57</td>
<td>147</td>
<td>205.36</td>
<td>19.98</td>
<td>9.73</td>
</tr>
<tr>
<td>5</td>
<td>1961-62</td>
<td>180</td>
<td>279.46</td>
<td>27.29</td>
<td>9.76</td>
</tr>
<tr>
<td>6</td>
<td>1966-67</td>
<td>200</td>
<td>216.37</td>
<td>21.51</td>
<td>9.94</td>
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<tr>
<td>7</td>
<td>1971-72</td>
<td>220</td>
<td>310.15</td>
<td>31.13</td>
<td>10.04</td>
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<tr>
<td>8</td>
<td>1977-78</td>
<td>287</td>
<td>673.29</td>
<td>64.61</td>
<td>9.59</td>
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<tr>
<td>9</td>
<td>1981-82</td>
<td>320</td>
<td>873.42</td>
<td>84.37</td>
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<tr>
<td>10</td>
<td>1986-87</td>
<td>354</td>
<td>852.02</td>
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<tr>
<td>11</td>
<td>1990-91</td>
<td>385</td>
<td>1223.38</td>
<td>120.47</td>
<td>9.84</td>
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</table>
### TABLE-2

**COUNTRYWISE PRODUCTION OF SUGAR (x 1000 t)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>INDIA</td>
<td>13,300</td>
<td>13,040</td>
<td>11,942</td>
</tr>
<tr>
<td>BRAZIL</td>
<td>9,200</td>
<td>7,835</td>
<td>7,793</td>
</tr>
<tr>
<td>CUBA</td>
<td>7,400</td>
<td>7,623</td>
<td>8,156</td>
</tr>
<tr>
<td>USSR</td>
<td>6,900</td>
<td>9,130</td>
<td>9,565</td>
</tr>
<tr>
<td>USA</td>
<td>5,951</td>
<td>5,599</td>
<td>5,220</td>
</tr>
<tr>
<td>THAILAND</td>
<td>4,700</td>
<td>4,006</td>
<td>3,506</td>
</tr>
<tr>
<td>FRANCE</td>
<td>4,402</td>
<td>4,743</td>
<td>4,198</td>
</tr>
<tr>
<td>F.R. GERMANY</td>
<td>4,160</td>
<td>4,675</td>
<td>4,004</td>
</tr>
<tr>
<td>MEXICO</td>
<td>3,780</td>
<td>3,612</td>
<td>3,408</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>3,140</td>
<td>3,612</td>
<td>3,844</td>
</tr>
<tr>
<td>INDONESIA</td>
<td>2,446</td>
<td>2,311</td>
<td>2,225</td>
</tr>
<tr>
<td>SOUTH AFRICA</td>
<td>2,404</td>
<td>2,168</td>
<td>2,277</td>
</tr>
<tr>
<td>PAKISTAN</td>
<td>2,307</td>
<td>2,100</td>
<td>2,017</td>
</tr>
<tr>
<td>OTHER COUNTRIES</td>
<td>43,037</td>
<td>42,979</td>
<td>40,709</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>1,13,097</td>
<td>1,13,764</td>
<td>1,08,864</td>
</tr>
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</table>

### TABLE-3

PER CAPITA CONSUMPTION OF CENTRIFUGAL SUGAR IN SOME COUNTRIES
(YEAR 1989)

<table>
<thead>
<tr>
<th>SI. No.</th>
<th>Countries</th>
<th>Kgms in Raw Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>E.E.C.</td>
<td>39.0</td>
</tr>
<tr>
<td>2.</td>
<td>U.S.S.R.</td>
<td>47.9</td>
</tr>
<tr>
<td>4.</td>
<td>Canada</td>
<td>40.0</td>
</tr>
<tr>
<td>5.</td>
<td>Cuba</td>
<td>68.0</td>
</tr>
<tr>
<td>6.</td>
<td>Jamaica</td>
<td>53.0</td>
</tr>
<tr>
<td>7.</td>
<td>Mexico</td>
<td>47.6</td>
</tr>
<tr>
<td>8.</td>
<td>Brazil</td>
<td>50.2</td>
</tr>
<tr>
<td>9.</td>
<td>Bangladesh</td>
<td>2.6</td>
</tr>
<tr>
<td>10.</td>
<td>Israel</td>
<td>55.4</td>
</tr>
<tr>
<td>11.</td>
<td>Pakistan</td>
<td>19.2</td>
</tr>
<tr>
<td>12.</td>
<td>Indonesia</td>
<td>14.5</td>
</tr>
<tr>
<td>13.</td>
<td>Burma</td>
<td>6.4</td>
</tr>
<tr>
<td>14.</td>
<td>China</td>
<td>27.3</td>
</tr>
<tr>
<td>15.</td>
<td>Iran</td>
<td>18.5</td>
</tr>
<tr>
<td>16.</td>
<td>Malaysia</td>
<td>37.4</td>
</tr>
<tr>
<td>17.</td>
<td>Fiji</td>
<td>50.6</td>
</tr>
<tr>
<td>18.</td>
<td>South Africa</td>
<td>30.9</td>
</tr>
<tr>
<td>19.</td>
<td>Australia</td>
<td>50.9</td>
</tr>
<tr>
<td>20.</td>
<td>India</td>
<td>13.2*</td>
</tr>
<tr>
<td>21.</td>
<td>World Average</td>
<td>20.9</td>
</tr>
</tbody>
</table>

*Excluding 11.0 Kgs Gur and Khandsari sugar consumption.

(Source—Indian Sugar Annual Number September 1991)
Fig. 1. FLOWSHEET OF THE PROCESS
SUGAR MANUFACTURE IN INDIA
Fig. 2. LAYOUT OF SUGAR MILL
Fig. 3. GLUCOSE, FRUCTOSE AND SUCROSE.
2. SUGARCANE FROM FIELD TO FACTORY

A. CANE QUALITY

1. COMPOSITION OF CANE

1.1. Sugarcane fed to mills for processing contains besides the water insoluble fibre, sugars, salts and organic matter dissolved in water, some of them being in colloidal state. The composition of cane is a function of cultivation practices as also the soil and climatic conditions and is therefore bound to exhibit wide variations from area to area and region to region. Nevertheless the major constituents of sugarcane are sucrose, reducing sugars, fibre and salts which exert profound influence on the economic aspects of cane sugar production. The principal components of sugarcane, along with their role in manufacturing operation are described below in brief.

1.2. Sucrose & reducing sugars—Sucrose, commonly known as cane sugar, is a disaccharide belonging to the family of carbohydrates and is composed of two monosaccharides glucose and fructose condensed together. Sugar solutions are stable under neutral conditions of pH and moderate temperatures. They are however, susceptible to microbial action which results in formation of undesirable fermentation products at the expense of sugar. The cane juices thus form ideal media for growth of microorganisms at atmospheric temperatures. The conditions maintained in the process operations are essentially based on preserving sucrose taking into account the above factors which contribute to decomposition of sucrose due to physical, chemical or microbiological causes. Under the action of acid the sucrose solution is decomposed into invert sugar i.e. glucose and fructose, the reaction commonly referred to as inversion, which is accelerated by high temperatures. The enzyme invertase also brings about this hydrolysis of sucrose at room temperature.

The important monosaccharides present in cane juice are glucose and fructose. Termed as reducing sugars, these occur in abundance in growing and immature portions of cane but decrease in the lower parts of cane stalk.

Immature cane is rich in reducing sugars which decrease as cane reaches maturity but once the maturity phase is crossed they tend to increase. The invert sugar formed by inversion of sucrose shows negative specific rotation, on account of higher levorotatory activity of fructose over the dextrorotatory power of glucose or dextrose. The reducing sugars are sensitive to alkaline conditions being decomposed into colouring compounds and organic acids under influence of alkali. They play an important role in determining the final loss of sucrose in the final molasses - a waste product of sugar manufacture - in as
much as reducing sugars reduce the solubility of sucrose in water. Sucrose and reducing sugars on prolonged heating form brown coloured component known as caramel.

1.3. Mineral matter—The principal cations in the mineral matter of cane juice are potassium, calcium, magnesium and silica while the anions are phosphates, chlorides, sulphates. The mineral matter content is maximum at the top and growing portions of cane while it tends to reduce in the lower-most internodes of the cane. The mineral constituents and mainly the potassium salts which constitute over 60% of the total ash are mainly responsible for the retention of sucrose in the final molasses.

1.4. Organic constituents—pH of cane-juice is around 5.2 - 5.4 on account of the presence of organic acids, out of which aconitic acid forms a major portion, the remaining being citric, oxalic, succinic as also a number of amino acids; prominent amongst whom is aspartic acid. Amino acids are found to decrease with advance of maturity but increase again when cane becomes over-mature. Proteins are present in small amounts and are removed to a considerable extent in clarification.

The naturally occurring colouring compounds are chlorophyll, carotene and xanthophyll which are removed in process during clarification. However, polyphenols contribute to colour formation in process. Among the high molecular weight organic compounds may be mentioned gums, dextran, the latter being the products of microbiological infection of damaged cells of the plant, mainly by the action of Leuconostoc Mesenteroides while the gums are soluble polysaccharides of the plant. Deterioration of sugarcane after harvest results in increase in the amount of dextran and gums. The cane tops are rich in polyphenols and organic acids.

1.5. Fibre—The water insoluble part of cane stalk, commonly known as fibre contains around 40% Cellulose, 30% hemicelluloses and 15-20% pectin, with small amount of mineral matter. The cellulosic portion of this fibre has high potential for conversion into commercially valuable products like paper boards etc. This fibrous portion of cane constitutes the main fuel for generation of steam and electric power in sugar plants.

2. CANE QUALITY IN DIFFERENT REGIONS OF INDIA

From the point of view of Agroclimatic conditions under which sugarcane is extensively cultivated, the country can be divided into three major regions—

(a) Deccan tract comprising Maharashtra and major parts of Karnataka and Gujarat.

(b) Southern starts of Andhra, Tamilnadu, Kerala and Southern parts of Karnataka.

(c) North Indian states of UP, Bihar, Punjab and Rajasthan.

As is well-known the climatic conditions have a great bearing on the maturity and sugar build-up in sugarcane. The important composition characteristics of the cane quality which influence the process of manufacture, sugar recovery and finally the productivity in process of manufacture in different regions are as under—
(a) Deccan—Cane composition in Deccan tract is characterised by high sucrose 13-14.5%, medium fibre 12.14% and low non-sugars. The reducing sugars are in the range of 0.4 to 0.7% while ash varies from 0.4 to 0.8% juice. The CaO content of raw juice is around 800-1100 mgms per litre. In the early part of the crushing campaign when cane is immature the sucrose content is 11-12% while juice purities are about 80 which rise with the advance of maturity to 87-88 when the sucrose content reaches peak of about 14-14.5% cane.

(b) South—This is low recovery region, where the pol in cane ranges from 10 to 12% while the juice purities lie between 78-82. The reducing sugar content is about 1.3% while the ash content is around 0.5-0.6%.

(c) North India—The canes of this region have high fibre 13-16% and low sugar content 10-13%. The juices are rich in phosphate (300-400 ppm) but contain low CaO. The reducing sugar content of juice varies between about 0.4 to 1% while the mineral matter i.e. ash ranges from 0.5 to 0.7%.

Notwithstanding the limitations imposed by climatic and other natural factors, modern cultivation practices based on research work of the various institutes, together with development of new varieties hold promise of improving the quality of cane in different regions of the country. Examples that can be cited in support of this, are the southern part of Gujarat or some factory areas of Punjab and West Uttar Pradesh where substantial rise in recoveries has been recorded in the last decade as a result of varietal changes and application of results of Agricultural research.

3. FIELD TO FACTORY

3.1. Cane being perishable raw material susceptible to microbial deterioration, it is the primary function of the cane supply section of the factory to see to it that the harvested material is available to the processing unit with minimum possible delay since deterioration of raw material resulting from staling would ultimately lead to reduction in the recoverable sugar. The factors which have significant bearing on the quality of sugarcane from the point of view of recovering maximum sucrose in bags are—

(a) time lag between cutting to crushing.

(b) extraneous matter accompanying cane. These are discussed below.

3.2.(a) Post harvest deterioration—The problem of post harvest deterioration of sugarcane has engaged the attention of the technologists all over the world. This deterioration is a function of a number of factors such as

(a) atmospheric temperature and humidity.

(b) burning before harvest or green cane harvesting.

(c) mode of harvesting like whole stalk harvesting or chopper harvesting system and most importantly.

(d) the time lag between cutting in the field to crushing in mills.
Under Indian conditions with the practice of manual harvesting whole stalk cane, the
studies conducted so far relate to the deterioration occurring on account of delay in
processing the cane after harvest under different climatic conditions mostly without
burning though some work has been reported on the combined effect of burning before
sugarcane cutting and the time element between cutting to crushing. Work at Jalander
under conditions of comparatively low temperatures—max. 31°C min. 4.8°C—showed the
loss of sucrose percentage cane of 0.5-1% after one day, increasing to 3.5-4% after eight
days accompanied by increase in reducing sugars from 0.3% to about 3% for the
respective period as the extent of deterioration was found to be different for different
varieties.

Experiments at the National Sugar Institute point to heavy deterioration in quality in
summer even with 24 hours' storage which can be arrested by spraying the cut ends with
formalin solution which inhibits bacterial growth. Studies conducted in Niphad factory
area in Maharashtra have shown loss of weight of cane and sucrose % even after 8 hours,
of harvesting increasing gradually thereafter up to 72 hours—the duration of experiment
in different months November to April. This loss increased with day temperatures.
Amino acid content in cane is reported to increase after 48 hours of harvest. Covering the
cut cane by trash or spraying water has been found to be helpful in reducing the loss due
to staling.

In regard to burning of cane fields prior to harvesting according to work at the National
Sugar Institute, Kanpur burnt cane standing in the field undergoes no deterioration.
However, harvested burnt cane shows rapid deterioration after 2-3 days. On burning the
cane greater fall in weight and sucrose content are observed than green cane in a
standing crop. Investigations by Foster in regard to burning of cane field reveal that the
temperature in moderate fire rises above 80°C for 8 seconds at depth of 1.5 mm. below
surface which indicates that approximately 20% of the outer portion of sugarcane would
be subjected to this temperature, which in effect is bound to lead to dehydration and
formation of coloured products from sucrose. Burning results in loss of protective wax
coating and moisture in cane and depending on the intensity of burn the sucrose loss can
be as high as 5% compared to unburnt cane, accompanied by formation of dextran. All
these considerations justify the great interest evinced of late in Florida, Australia etc. in
developing green cane harvest systems.

Apart from the damage caused by burning, the staling after harvest brings about much
higher sucrose loss in chopped billets compared to whole stalks for the obvious reason
that more cut portions of sugarcane are exposed to atmosphere and microbial action. This
loss is essentially function of time and the extensive work on this aspect points to
restricting the time lag between cut to crush to 12-14 hours only in the case of cane cut by
chopper harvester. In essence it may be stated that

(a) Burning leads to loss of recoverable sucrose compared to unburnt cane.

(b) Staling of cane cut into small pieces causes greater loss, than the whole stalk, since
staling of chopped cane for more than 18 hours, has been found to lead to formation
of dextran under action of Leuconostoc Mesenteroide which increases with delay
between cutting and processing.
 Loss of sucrose is accompanied by formation of dextran and gums which are harmful from process point of view.

3.3. Extraneous matter—The extraneous matter which accompanies the cane to factory can be
(a) green immature tops, (b) dry trash, (c) soil. Mechanisation of harvesting brings more non-cane extraneous matter to the factory and manual cutting is to be preferred wherever possible, from this angle. Extensive investigations have been conducted in India about the technological aspects of the non-cane matter entering process of manufacture, based on the main premise that any non-sucrose entering process of sugar manufacture takes away some sucrose while leaving the process. To be more precise the sucrose loss on account of immature cane tops and trash can be attributed to following factors—

(i) lower purity of juices extracted than those from the normal cane result in more molasses.

(ii) loss in milling is increased due to unwanted fibre material which does not give normal juice in the extraction system.

(iii) extra load is imposed on the process of juice extraction and sugar crystallisation without proportionate gain.

(iv) undersirable impurities introduced in process create problems in operation.

(v) soil increases wear of machinery like knives, mill rollers etc. and much of it finds its way to boiler.

4. 4.1. As a matter of fact the manual harvesting and loading for transport to factory should give clean cane free from unwanted tops, leaves, dry trash, sand etc., with proper operations by trained disciplined labour. However, for some reason or other, this aspect of control of extraneous noncane matter accompanying cane going for processing has not received adequate attention. At Shamli factory in UP percentage of the cane tops known as ‘Agola’ was estimated to be over 15.00 in one season, while the purities of these tops were found to range from 14.8 to 36.5 lower levels being observed in the early part of the campaign8. Investigations carried out at Phaltan Sugar Works, Sakharwadi, have revealed that the unwanted tops contain 4-7% higher fibre and yield juices with 15-20% higher conductivity and nearly twice the amount of reducing sugar compared to the rest of the portion of cane. The colouring matter was also found higher by 35% and purities lower by 5-10 units in the case of juices from tops of mature cane than those from remaining stalk. The colouring matter even after sulphitation of both these juices separately was found to be higher by 50% in juices from tops most probably due to the phenolic bodies9. Work on estimating losses on account of trash in cane at Sameerwadi Mills, as well as loss of weight of clean cane has shown the cost escalation of production of sugar to be Rs. 45.55 and Rs. 25.43 for every one percentage addition of trash and top respectively under price structure prevailing in 198010. Effects of different levels of extraneous matter on molasses purity and sugar recovery have been worked out and reported. Needless to state that the harmful effects due to unwanted tops would be more pronounced with supply of immature cane to the factory but even with mature cane utmost care has to be exercised for avoidance of extraneous matter. It has been found that the extraneous
unwanted non-cane material being fed to mill varies from 6 to 15% depending on the state of maturity as also the extent of control on the quality of harvesting. It is of utmost importance to bring down this non-cane matter to 2-4% levels for improving production efficiency and sugar recovery for which rigid control needs to be exercised at all levels in harvest and supply system.

4.2. In regard to mechanised harvest and supply the problem of extraneous matter assumes serious proportions. Even with chopper harvester operation the extraneous matter varies between 6-10%. Preharvest burning reduces the green matter and dirt content of mechanically harvested cane, but the Queensland experience shows that burnt cane billets are more susceptible to Leuconostoc attack with formation of dextran than green cane\textsuperscript{11}. The whole stalk harvester has been found to give 10-16% noncane unwanted matter under different conditions. In Hawaii the proportion of extraneous matter like tops, leaves, rocks, soil etc. in the gross cane delivered to factory being as high as 25-40% cane cleaning laundries are essential adjuncts to sugar mills. Soil and climatic conditions determine the extent of soil and trash that will inevitably accompany mechanically harvested cane.

Combine harvesters were found to yield around 8-12% total trash in burnt cane in clay soils as against 9.4 to 14% in sandy soils in Brazil, while hand-cut and mechanically loaded total cane gave trash percent of 1.5 to 5.88.\textsuperscript{12}

Machine harvesting coupled with mechanised loading would yield not only higher fibrous non cane matter but also soil, sand, small rocks etc. The soil and dirt going to sugar mill can be 1 to 1.5% of the cane and creates problems at different stations in the following way:

(a) heavy wear of preparatory equipment, mill rollers, valves, pipes etc. upto raw juice stage.

(b) settling difficulty in clarification and higher mud load.

(c) increase in molasses loss due to dissolved salts. Cleaning the cane with water helps overcome the above processing difficulties but entails loss of sugar in the wash water estimated in Mauritius to be 0.22%.\textsuperscript{13}

5. QUALITY CONTROL

It would thus be obvious that control on quality of cane is not only related to sugar and non-sugar content of cane but also to the two vital factors discussed above viz. staleness and extraneous matter content. The sugar factory laboratory has undoubtedly an important role to play in assessing the quality in totality taking into account the requirements of efficient processing of raw material and monitoring of the cane quality would involve collection and dissemination of data pertaining to—

(a) pol % cane

(b) extraneous matter in cane

(c) time lag between 'cut' to 'crush'.

With close coordination between field staff and the laboratory which would serve as monitoring agency evaluating the quality of cane supplied to factory the overall performance of the process is bound to improve.

In India cane price is related to weight of gross sugarcane delivered at the factory, irrespective of the recoverable sugar as against the practice adopted in developed cane regions, of USA, Australia etc. where the determination of CCS. i.e. the recoverable sugar constitutes the basis for cane payment. In the context of Indian conditions therefore control on quality of cane with respect to the extraneous matter, staleness and recoverable sucrose assumes special significance. Efforts were made three decades back by the National Sugar Institute, Kanpur to develop system of payment for cane on the basis of sugar contents and considerable work was done to evolve system suitable for Indian conditions. But the adoption of this scheme could not make headway for various reasons, one of them being the large number of cane suppliers (5,000 to 40,000) with small holdings, whose consignments have to be evaluated for quality assessment.
REFERENCES

B. CANE HARVESTING & SUPPLY

1. MATURITY

At the end of the growth phase sugar-cane reaches a stage when maximum sucrose built up is observed, and the cane is deemed to be fully mature. The period of maturity is followed by a decline phase marked by loss of sucrose and increase in nonsucrose components as well as fibre content. The interests of both cane growers and processors are best served by harvesting the cane when it is fully mature for extracting maximum sucrose in as much as both immature and over-mature canes yield, during processing, less sucrose on account of lower sugar content and presence of more non-sucrose impurities which give rise to higher sucrose loss as compared to mature cane. Immature cane contains more water and reducing sugars, but low fibre and sucrose while the over-mature phase is characterised by high fibre and organic impurities, but low water. In the context of working of Indian Sugar Industry where cane payment is based on weight of the material, maturity based harvesting has special significance particularly from the point of view of obtaining high sucrose recoveries in sugar mills.

2. FORCING MATURITY

It is possible to force the pace of ripening of cane at the end of growth phase of the plant by adopting certain practices whose efficacy is established. Withdrawal of irrigation 2-3 weeks prior to harvest is an inexpensive way of ensuring maximum sugar content in cane, while forcing ripening of cane by spray of chemicals like Polaris, Ethrel, Glyphosate, Sodium metasilicate on cane crop has been found to increase recoverable sugar and is being practised in many sugarcane growing areas.

Chemical Spray of 'Ethrel' has resulted in reduction in leaf area and increase in sucrose yield per hectare. Multiple applications of this chemical increases ripening response to spraying and reduction in CO₂ uptake as also rate of transpiration. Polaris has been probably the most widely tested chemical ripener in different countries like Australia, Phillipines, Brazil etc. and has proved very effective in increasing sucrose yield per hectare. Polaris is supposed to prevent sucrose degradation by suppressing acid invertase activity, and stimulating accumulation of sucrose in stalks.

A number of field trials with application of different chemical ripeners like 'polaris', cycocil etc. have been reported in India, and good results have been obtained in different regions, as for instance at Bardoli in Gujrath Cycocil and Glyphosine at 0.5 to 2.5 kg. per hectare have proved beneficial in hastening maturity of crop. Work at Padhegaon research station in Maharashtra on spray of Polaris at the rate of 4 kg/ha. has shown increase in CCS. content of variety CO740, maximum benefit being obtained 3 months after spraying and the crop yields remaining unaffected. Foliar spray of Sodium metasilicate and Polaris in Tamilnadu on experimental scale has yielded positive response in respect of recovery. All this experimental work points to necessity of forcing ripening of cane by foliar spray of different chemicals as above on immature cane crop to
be harvested in the early part of crushing campaign. However suitability and choice of particular chemical will be governed by the ultimate economics which can be worked out after conducting large scale trials on different varieties.

3. CONDITIONS IN INDIA

The cane crushing season in India extends from October to June and it is common to notice low recovery in the first two months, gradually rising till it reaches peak in January, February while it starts declining thereafter, the drop being sharp after April i.e. in summer months. In a season lasting over six months the difference between the lowest recoveries, recorded in the early as well as last periods of the season and the peak recovery could be as high as 2 to 3 percent on cane. It would certainly make a lot of difference to the factory to bring it down to a reasonably low level in the interest of raising the average sugar recovery for the season, which is possible by a series of measures such as—

(a) crop planning involving cultivation of early ripening, midripening and late ripening varieties.

(b) forcing maturity by spray of chemicals.

(c) harvesting on the basis of maturity.

In view of the comparatively small land holdings in the sugar cane areas the tasks are formidable but sustained efforts on the above lines are bound to yield high returns.

Crop planning, on the basis of cultivation of varieties with different maturity periods has been successfully practised in some parts of Maharashtra, Tamilnadu, and Gujrath which has led to increase in average recoveries in the past decade or so6. Induced maturity by spray of chemicals has been tried out of experimental basis but not adopted on large scale.

4. MATURITY WISE HARVESTING

Scheduling of harvesting procedures, wherein the priorities for harvesting crops in fields are on the basis of cane maturity has been established to be an effective method by number of trials conducted in India. The determination of brixes of juices from selected internodes of cane samples of standing crop, with the help of hand refractometer forms the basis of this system since these brixes are highly correlated with sugar content of cane. According to one method the brixes of top and bottom internodes of the standing canes are determined and expected recoveries worked out. The fields with high expected recoveries are accorded priorities in respect of harvesting. Work done at the National Sugar Institute Kanpur has helped evolve standard procedure for refractometric survey based on large scale trials at different factories and has positively shown the usefulness of conducting harvesting in succession to maturity.7 The procedure worked out by Sen which formed basis of this work is as under—
The number of stools selected as representative sample from half an acre is 20-25 for immature cane, which is reduced as ripening advances. Specially devised needles with a reservoir are used for puncturing middle internodes and collecting juice samples which are analysed for brix with the help of hand-refractometers. The results of field surveys are tabulated and harvesting calendar prepared on the basis of priorities determined by the brixes, higher the brix higher being the expected recovery. Surveys are commenced 3-4 weeks prior to scheduled dates of crushing campaign which in turn depends on the total availability of cane crop for processing unit. Every factory can work out the correlation coefficient between the middle internode brixes of cane, and expected recoveries.

In the method based on determination of the brixes of top and bottom internodes, representative samples of cane from field are analysed with the help of hand refractometers and ratios of top to bottom brixes worked out. This method is dependent on the concept that high level of maturity is decided by ratios approaching one since the difference in brixes of tops and bottom tends to decline as maturity advances.

In the factory managed farms of Maharashtra, the practice of digging the canes was followed in the case of 'Adsali' or plant crops where ratoons were not desired and higher yields of nearly 8 t/h were reported but this operation though beneficial is highly labour intensive.

The practice of deciding priorities of harvesting on the basis of age of the crop i.e. the dates of planting prevailing in most of the factories due to simplicity of nature cannot be considered to be scientific in view of the fact that ripening is determined by several factors like soil characteristics, methods of cultivation etc., besides time of planting and study of maturity levels by preharvest refractometric survey is bound to raise the sucrose recovery in the initial stage of grinding season thereby enabling the factory to obtain maximum sucrose from a particular crop.

5. HARVESTING METHODS

Harvesting operation in the field comprises following major steps.

(a) cutting the cane at the base,
(b) removing the tops and trash.
(c) stacking the clean cane.
(d) loading the vehicles.

The system of cane harvesting has some special features such as-

(a) necessity to cut the cane sticks close to the ground in view of the fact that the lowermost internodes are rich in sugar and thus form precious part of the plant.

(b) the plants to be cut are not always erect and may be lying in any direction, which requires making them upright for proper cutting.

(c) the cylindrical cane stalks are of 2-3 cm. diameter and naturally offer resistance to cutting.
the top internodes and leaves have to be cut and separated.

side shoots, diseased stalks and late tillers are to be excluded from supply.

the quantities to be handled are pretty high as for instance a normal 2000t. cane per
day plant will need supply of around 2200-2500 t. per day, which would call for
operating in fields with areas of 20-40 hectares depending on the yields. For feeding
plants of still higher capacities ie. 4000-7000 t. per day the areas to be covered are
proportionately increased and the activity centres could be spread far and wide and
not necessary contiguous.

dry trash as also any soil adhering to cane have to be removed.

The cane thus harvested is loaded without loss of time on transport vehicles for supply to
factories. The overall efficiency of the system is determined by the meticulous operation
of every stage whether with or without the aid of machines, in as much as the
productivity of the processing unit is influenced to a large extent by the supply of clean
and fresh cane.

All these field operations are manually carried out in the Indian Industry as against the
system followed in many countries, particularly the regions of the developed countries,
where the above operations are carried out by machines. In whole stalk harvesting the
cutting of the standing cane, removing the tops are the jobs of harvesters. The harvester
operations in many places are preceded by setting fire to fields for burning of dry trash.
The harvester is fitted with adjustable top cutting and base cutting mechanisms and is
ideally suited for erect cane. The machine cuts the cane and windrows it in heaps of 3 to 8
rows in one pile row. In case the prior burning of fields is not practised the heaps are
burnt for removal of dry trash, while loading is done by grab loaders into transport
vehicles. Another design of harvesting machine operating in Hawaii is push rake type
harvester which can handle tangled and heavy yield crops. The machines cut stalks at the
bottom but not the tops and windrows the same, loading being effected by continuous
loaders, which remove some tops.

In combine harvester developed in Australia, the cane stalks cut at the base are drawn in
the machine and cut into billets which travel in an elevator where the trash is blown off
by air from blower fans fitted in the machine. The cleaned billets are fed continously to a
tractor trailer moving along the side of the machine. The cane thus harvested being more
susceptible to deterioration than whole stalk cane has to be processed within 12-16 hours
of cutting.

In Indian Industry, the tasks of cane cutting chopping the tops and removal of trash are
performed with the help of long knives. Bundles of cane thus harvested are transferred to
bullock cart manually. A bullock cart usually carries 0.75 to 1.51. sugarcane to the factory.
Now-a-days the bullock carts are fitted with rubber tyres, which renders transport easier
and speedier. Truck and tractor drawn trailors are being increasingly employed for
transporting cut cane from fields to factories and are more suitable than bullock carts for
transport over long distances. The trucks in many cases are fitted with slings for holding
bundles and facilitating unloading at the factory carrier. With proper control on
harvesting it is possible to supply clean cane with minimum extraneous matter with this
system. In some joint-stock factories of Maharashtra established in thirties and early
forties, railway system was established on huge farms attached to the factories, the entire plantation cane being transported to factories by rail. The cane cutting and loading the wagons were manually performed. In some parts of North India, harvested cane is brought to rail lines and transported to factories situated near railway stations in wagons. It thus is obvious that even though for short distances of 10-15 k.m. transport by bullockcarts will be suitable, for longer distances mechanised road transport is inevitable for efficient management of harvest and supply of cane. The factories in Maharashtra organise their harvesting and transport of cane by employing harvesting labour.

Harvesting of cane is a strenuous operation involving considerable manual labour which is becoming scarce and as the living standards in rural areas improve, labour is becoming reluctant to take up this job in developing countries. In India also shortly a stage would be reached when the manual jobs in Agriculture will have to be mechanised for reducing the cost of production and to overcome the problem of paucity of labour which inevitably results in increase of wages. Of all the farm jobs the cane harvesting being one of the most strenuous ones, it is but natural that this would be mechanised in future following the practices adopted in countries with high standards of living such as Australia, U.S.A., etc. and also some developing countries in South America, Taiwan etc. The mechanisation of this operation would essentially call for some modifications in cane farming practices, to facilitate the operations of machines as under—

(a) Uniform row cane spacing of about 1.75 m which calls for change in the cane planting method.

(b) The cane varieties have to be so chosen as to give strong root system to prevent uprooting by harvesters.

(c) Erectness of cane facilitates proper topping.

(d) Canes should have easy detrashing and good burning characteristics.

(e) uniform planting and growth are essential.

(f) Fields with recumbent and lodged cane, when harvested by machine lead to heavy loss and high trash in cane.

(g) Planning of fields for manoeuvrability of machines is essential.

(h) Removal of stones, trees, from fields are necessary.

The problems associated with mechanical harvesting can be briefly stated as under.

(a) High extraneous matter accompanying the cane (10-15%) increases loss of sugar in cane processing.

(b) Loss of cane in fields is inevitable depending on the recumbent or lodged cane percentage or uneven growth of the cane in fields.

(c) The systems are highly capital intensive and highly power consuming.

(d) Thorough maintenance of the equipment is essential for obtaining the desired productivity per unit.
(e) Burning of fields, for removal of dry trash, usually practised, results in cane with higher rate of post harvest deterioration than in the case of unburnt cane.

(f) Green cane harvesting enables preservation of tops but increases extraneous matter.

(g) In the case of Chopper harvester the extraneous matter is reduced compared to whole stock harvester but the post harvest deterioration rate is much faster after 12 hours.

The quality of cane manually harvested and loaded for transport from field is always superior to the machine harvested cane in respect of extraneous matter and the maximum amount of sugar rich portions of cane close to the ground and in the Indian context careful thought has to be given before replacing labour by machines. Some peculiar features of Indian Cane Agriculture and Industry are:

(a) Small holdings of land of cane growers
(b) low sugar recoveries in many regions
(c) inadequate facilities for heavy machinery maintenance

Moreover the heavy machinery employed in modern harvesting systems are highly energy consuming which would, in the present Indian scenario of escalating costs of fuels and dependence on imports for petroleum products, not be economical to operate.

Perhaps immediate alternative to complete manual operation would be (i) to mechanise cutting and (ii) employ labour for cleaning the cut cane and load the same on transporters thus paving the way for partial mechanisation as attempted at Walchandnagar where development work on devising a suitable harvesting system had been undertaken.13

Irrespective of the system of harvesting and transport, the cost of operation will be governed by the productivity of the machine operation as well as labour employed, while the overall efficiency of the system will be determined by undermentioned vital considerations:

(a) supply of clean cane free from extraneous matter
(b) time loss between harvesting and milling has to be minimum preferably 12-24 hours.

It is desirable to establish efficient communication line between the central controlling office of the Agriculture Department of the factory and the areas where harvesting operations are going on to regulate the harvesting and supply of cane so as to supply fresh adequate cane to mills. Wireless system have been installed in some Indian Sugar Mills for communications between factory and fields.14

Perfect coordination between harvesting and transport with the milling operation can be established only through proper communication between the two activities in order to avoid staling of cut cane while at the same time maintaining the desired rate of grinding which can ultimately lead to high sugar production and reduced cost of production. Against this backdrop every factory has to carefully analyse each operation of the entire system and devise strategies for cutting the cost of supply of cane to the mill in view of the escalating costs of the inputs.
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10. ‘Cane Sugar Hand Book’ by Meade and Chen, 10th Ed. (1977) p. 8 & 9,

Also literature by harvester manufacturers.


3. **JUICE EXTRACTION**

**A. MILLING**

1. The extraction of juice from cane constitutes the first stage of the entire process of cane sugar manufacture, wherein the object of separation of juice from the fibrous portion of the cane is accomplished by employing heavy machinery. The sugarcane plant is essentially composed of two types of fibre, the interior soft pith which holds sugar rich juice, and the outer hard portion known as rind, containing juice with high impurities. Before the dawn of machine age, vertical rollers of wooden or stone construction, were employed for squeezing out juice, the energy being provided by animals and human labour, which later gave place to massive machines, the basic principle remaining unaltered. In cane juice extraction, the cane tissues are disintegrated and juice removed by compression and squeezing supplemented in some cases by lbdviation.

2. **CANE WEIGHMENT**

   Cane weighment is essential for two reasons, one is to serve as method for payment to growers, on the basis of weights and the other is from the point of view of its importance in chemical control, wherein the cane weight forms the basis of arriving at weights of bagasse. Cane carrying bullock carts, or trucks or trailors are weighed at the entrance of the cane yard on platform weighing scales care being taken to find out tare weights after the transporters are unloaded, for finding out the actual cane weights. In old designs of weighing scales the weights are determined by manual operation involving sliding weights on weighing arm, whereas modern weighment machines are equipped with dial indicators for weights as also card punching arrangements, which obviously is a foolproof system.

   In most of the factories the distance of the weighing scales is about 50-100m. from the cane carrier and the weighed transporters are lined up inside the yard. Unloading cane on ground in the yard is avoided as it involves double handling of cane though in exceptional circumstances like sudden major machinery breakdowns, this has to be resorted to.

3. **CANE CARRIERS AND CANE FEEDING**

   3.1. The function of this moving apron type conveyor, commonly known as cane carrier is to convey sugarcane from the yard to the mills. A cane carrier should have horizontal
portion of 30m., suitable for cane feeding and the inclined portion has a slope of normally 18°. It consists of two or three strands of chains to which are fitted steel slats overlapping by rounded edge. The width of the carrier is the same as the length of the mill rollers while the strength of the chain is determined by the quantity of cane to be handled and the drive is provided by electric motor, through variable speed gear so as to maintain speed varying from 3-10 m/min. which is usually about half the peripheral speed of the mills.

A split arrangement of this unit comprising two carriers is preferred as the partially cut cane from first carrier is overturned on the other which helps uniform cane preparation.

An auxiliary carrier known as feeder table provided with independent drive is installed at right angles to the horizontal portion of the main cane carrier, over which cane is unloaded. It is used for regulating feed to the cane carrier. This is essentially a wide carrier fitted with drag type chains conveying cane over an inclined table which has its feeding end about 2 m. above the top of the main carrier. It is provided with variable speed drive and runs at 1.5 - 5m. per min. i.e. at much lower speed than that of the main carrier to avoid sudden dumping of cane from its large area. A tumbler with arms running slowly in reverse direction to the flow of cane, fitted at the feeding end of feeder table prevents sudden dumping of large mass of cane.

3.2. Cane feeding—In modern plants major quantum of cane is transported from field to factory—nearly 70-80%—in trucks or tractor drawn trailors, the remaining being brought to factories by bullock carts from the adjoining areas mostly within a radius of 10-15 km. While the bullock carts are unloaded into the carriers manually by tilting, the truck or trailors, each carrying 5-10 tons cane are mechanically unloaded, manual operation being cumbersome and time consuming. The vehicles are fitted with usually chain slings equally spaced on the floor of the truck. The sling ends are joined after loading the truck or trailer, thus forming bundles of cane, to be lifted by overhead crane fitted with bars. At the carrier the bundle is lifted, conveyed to the feeder table and sling ends released with the sling left hanging at the end of operation when the bar is lifted. The entire operation is simple and quick, and has gained popularity in recent years.

Yet another type of unloader suitable for trucks, consists of overhanging chain rake assembly which can be moved up and down with the help of wireropes on both sides, passing over pulleys. The cane is pushed out of the back of trucks by lowering the rakes.

Mechanised unloading essentially involves the installation of overhead gantry with two or preferably three motion electrically operated crane, fitted with bar attachment for sling bundles or a grab, with a lifting capacity of 5-10 t cane. Since no unloading for stacking purpose is aimed at, the length and width of travel is limited to area required for unloading of transporters.

4. CANE PREPARATION

4.1. The object of cane-preparation is to cut cane into short pieces for feeding the mills as also to rupture the cells, without extracting juice. The preparatory devices commonly employed and installed before the milling tandem, are classified into three types—


(i) Knives which cut the cane to pieces.

(ii) Shredders which shred cut cane into long fine pieces.

(iii) Fibrizer system combining the features of both (i) & (ii).

Percentage of cells opened to the total, which is indicative of the extent of cane preparation, is 
(a) 50-60% in the case of two sets of knives run in the direction of carrier, 
(b) 85-90% with a combination of knives and shredder, while for unigrator or fibrizor it would be 75-80%. In the case of knives run in opposite direction to the flow of cane, the preparation index can be 65-70% depending on whether one or both the sets are revolving in reverse direction.

4.2. Cane kicker or equaliser—The cane kicker is installed on the carrier to prevent excessive cane being fed to cane leveller which causes jamming of the leveller set. It consists of a steel shaft directly coupled to a motor with arms or knives mounted on it, running normally at 50-100 rpm, in reverse direction to the flow of cane on the cane carrier. When arms or angles are secured to the shaft, the r.p.m. and power requirement are low but when knives are fitted and r.p.m. about 100 or so the power requirement is higher since some cutting action is also envisaged along with maintaining uniform feed to knives which forms the main function of this piece of equipment. In some factories before a shredder or a fibrizer an equaliser or leveller of the same design as a cane kicker is installed after the cane has passed through first one or two sets of knives to ensure even distribution of feed.

4.3. Cane knives

4.3.1. Cane preparation by knives essentially consists in disintegrating the hard rind, and nodes, and breaking the cane to short pieces which in effect increases the mill capacity and efficiency of juice extraction. It consists of forged steel shaft with cast steel hubs to which are secured knives in different planes. The shaft supported on double row ball bearings is coupled to a motor and revolves at about 600 rpm. Different designs of knives are adopted, some of which are of reversible blade types, while some are of bent or circular type. The knives are made of shock-resisting steel with stellited edges. The knives are enclosed in M.S. hoods attached to cane carrier frame and provided with bolted doors on top.

The pitch of the knives, i.e. the distance between two successive circles of knife rotation, is usually about 50 mm, but is reduced to 25 mm, or lower, while handling hard and thin canes in some sugar producing regions, by increasing the cutting planes.

The first set of knives known as leveller is installed over the carrier with clearance between the tips of knives and the carrier of 50-150mm, as it has to chop whole cane; while with the 2nd set of knives which cuts the partially cut cane from leveller the clearance is 30-50mm. This unit known as cutter is located at a distance of about 5-6 m. from the leveller set on the carrier. The efficiency of knives decided by the proportion of cut cane is dependent to a large extent on the clearance, which can be varied by adjusting position of knives and the motor.
4.3.2. Conventional practice of arranging the rotation of both the sets of knives in the direction of the moving cane carrier is not followed now a days and instead either the cutter or in some factories both the cutter and levellers are run in the reverse direction i.e. opposite to the movement of the carrier. Reversing the direction of knives involves higher power consumption but gives better cane preparation and requires modification of hood design.  

4.3.3. The power requirement of knives is dictated by the extent of preparation expected from each set and will in turn depend on

(i) The clearance between lowest extremities of knives and the plane of carrier,

(ii) fibre of cane and quantity of cane passing,

(iii) direction of rotation since reverse running involves higher power consumption compared to conventional running in the direction of the passage of cane.

The maximum power peaks cane be 400% of the mean power for whole cane and 250% of the mean power for chopped cane as per experience in Australian Sugar Industry. The normal practice is to install about 20 h.p./t.f.h. for levellers and 30 h.p./t.f.h. for cutters about 200% higher than the mean power load. The power peaks can be minimised by installing 'kicker' at the cane carrier before leveller and an equaliser before second set of cutters, when it is running in opposite direction to the cane carrier.

4.4. Shredder—Shredder is essentially a hammer mill adapted to the function of sugarcane pulverising and swing hammer type shredders of different designs are common in sugar producing countries including India. On forged steel shaft are fitted a number of steel discs to which are attached hammers with hard faced tips, and provided with hardened bush at the pin. The hammers revolve on pivots. Shredders are housed in thick steel plates, with inspection door provided at the discharge end. As the shredder starts rotating the hammers are thrown out radially by centrifugal force. The shredders rotate at 1000-1200 rpm. and are usually directly coupled through flexible coupling to electric motor or driven by steam turbines, the total installed power being about 20-26 HP. per t. fibre per hour, while actual mean-power consumption is 30-50% lower than this. Feed to Shreddar is from top which gets pulverised between the anvil bars and rotating hammers.

As the name indicates, this equipment shreds or tears the cane to pieces or rather pulverises it into long fluffy material with high bulk density, which in effect increases the capacity and extraction of the mill. One percent gain in extraction with Searby type shredder has been reported from Hawaii for 15 roller tandem. It is necessary that the feed to the shredder (after cane has passed through two sets of knives) is regulated by installation of equaliser before the same.

In Australia and South Africa heavy duty Shredders are employed, with hammers weighing about 15-20 kg. each and subsequently very high power consumption, nearly double that with Shredders operating in India. The obvious benefit is very high preparation Index of 90 or above with consequent increase in extraction. It must be clearly realised that the knives can disintegrate the cane to fine and short pieces, but the
preparation is not uniform and some uncut pieces are noticed after the cane has passed through knives. The shredder preparation results in long slivers, with a high degree of cell rupture; which is uniform and thorough. Shredder is always preceded by usual two sets of knives viz. leveller and cutter which cut the cane prior to feeding the shredder which is located at the head of milling tandem.

4.5. Unigrator or fibrizer—This ingenious preparatory device, which combines the functions of cutter knives and shredder, was developed by Victor Ducasse in 1971 and has gained popularity in recent years in Indian Industry. The rotor consists of a heavy duty special steel shaft on which are mounted a series of sturdy hubs. The special knives have cutting edges and two hammers projecting in opposite direction which act as hammers. The cutting knives are secured to the hubs and serve the dual function of cutting and shredding cane which has passed through the leveller set. The casing of the rotor assembly has two side walls, a top cover and chute fitted with spring loaded anvil whose position is adjustable. Special features of this machine are—

(i) fibrizer revolves in direction opposite to the flow of cane,

(ii) the casing is so designed as to first ensure cutting action on the cane, which is thrown into rear chute and anvil where shredding is brought about,

(iii) unlike shredder the chopper is preceded by only leveller,

(iv) total h.p. for the leveller fibrizer combination is 35-40 H.P./tf/hr. and rotation speed is 1000 r.p.m.

New designs of fibrizers known as ‘mincer’ or ‘comber’ incorporate the two major features of ‘unigrater’ viz., grate at the rear discharge chute and blades combining the features of hammers and knives. The results reported with these machines developed indigenously appear to be promising.

4.6. Influence of cane preparation—It is now an established fact that fine cane preparation is key to efficient milling in as much as it exerts influence on mill extraction as well as throughput. Fine preparation calls for higher power requirement for the preparatory devices like shredders and fibrizers, but results in reduction of power consumption at mills. In Australia great stress is laid on cane preparation by employing heavy duty shredders and the power consumed for cane preparatory devices is very high around 70-90% of the total power for mills whereas in Indian sugar mills the installed hp. for cane preparation is about 40-50% of the power of mill turbines.

5. MAGNETIC IRON SEPARATOR

With the advent of mechanical harvesting and field mechanisation, loose iron and steel pieces from machine parts find their way to sugar factory with sugarcane, when it becomes imperative to remove them before milling operation to prevent damage to machinery. A stage may be reached in Indian Industry in a decade or so to resort to mechanisation of cane harvesting owing to scarcity of harvesting labour and the factories receiving machine harvested cane will have to install tramp iron separators. These
electro-magnetic separators which are in the form of flat electromagnets or are cylindrical shaped are best placed with high speed carrier before the shredder or first mill as per mill design to avert damage to rollers. The efficiency of these separators in removing iron pieces and thus avoiding damage to processing equipment, in particular the mills is reported to be 80-90%.\textsuperscript{10}

6. MILLS

6.1. The disintegrated cane is fed to the first mill commonly known as crusher, of the series of three-roller mills-forming a mill train in which the subsequent mills perform the function of expressing the juice from bagasse soaked in water or imbibition fluid. In some old designs the first juice extraction of the prepared cane is carried out in a two roller crusher followed by three roller mill. Modern milling tandem comprises four, five or six-three roller mills, each roller being 760 mm. - 1100 mm. dia and 1520 mm. - 2200 mm. length respectively, usually the length being about twice the diameter. In India most of the modern mills are of 760 x 1520 mm size or 850 x 1700 mm size.

The modern mill head stocks in which the rollers are housed are cast-steel or M.S. fabricated and of robust construction. These are of king boltless type, with top and side caps of cast steel. The roller shells are of coarse grain cast iron, provided with circumferential V grooves. The shells are shrunk on cast steel shafts of high tensile strength, with square ends. The bed plates are of C.I. or Meehanite construction while the V shaped juice troughs below the mills are of copper or aluminium.

The roller bearings are white metal or gunmetal lined and provided with water-cooling arrangement. Each mill is equipped with hydraulic accumulators for top roller journals, for regulation of load on mills. Cast steel trash plate mounted on trashbeam, below the bottom rollers serves to guide the bagasse from feed roller to discharge rollers. Scrapers with C.I. tips maintain the grooves clean, the one for top roller being of floating type.

The drive for mills comprises a steam turbine connected to a system of gears for reducing the speed from 5000-9000 r.p.m. to ultimate 4 - 5 r.p.m. for the mills, the top roller of the three-roller mill being coupled to the transmission heavy gears through a tailbar, while the bottom rollers receive their motion by pinions connected to top roller pinion. As the turbine drive,

(a) gives good starting torque.

(b) permits of fairly wide variation in the speed of the mills, and

(c) is suitable for higher steam pressures (21-31 kg/cm$^2$).

(d) besides being compact and requiring less maintenance it has now replaced the former steam engines.

Furthermore the exhaust is not contaminated with oil as in the case of steam engines. Individual drive is preferred for mills to a combined drive for 2 - 3 mills since the former allows variations in the speeds of each mills. Final peripheral mill speed is maintained at about 10-16 m/min.
6.2. Roller grooves—The rollers have V shaped grooves, on the periphery of the shell, distributed over the entire length such that the distance between adjacent grooves, the depth and the apex angle of grooves remain the same for a particular roller. The grooves serve two-fold purpose: one to provide passage for juice extracted on compression and two to disintegrate the bagasse to facilitate juice extraction, and in any mill the system of cutting the grooves is such as to allow the teeth of the top roller mesh with the grooves of bottom rollers. The pitch of grooves i.e. the distance between axes of two successive grooves is gradually reduced from first to last mill as the fine pitch favours extraction which is important for last mills whereas coarse grooves serve to disintegrate bagasse due to differential peripheral velocities of meshing top and bottom grooves. In some countries, however the practice followed is to maintain uniform pitch throughout the mill tandem to reduce maintenance of spare rollers. However in Indian Industry, it is customary to maintain coarse grooving for first mill and gradually reduce the pitch along the length of the tandem, as for example, a mill of 760 mm. x 1500 mm. size crushing 130 - 140 tc/hr. will have first mill with 65 mm. pitch gradually diminishing to 25 mm. for the last mill.

The angle of groove varies from 35° to 55° the usual practice being to maintain acute angle for feedroller, wider for the top, while the discharge roller has groove of value lying in between the two. Acute angle of 35° at the feed facilitates good juice drainage, which is very vital at the feed side.

On the feed side, for improving extraction of juice, Messchaert grooves are provided for feed rollers. Messchaerts are deep grooves cut between two teeth, the width and depth from base of groove being generally 5-6 mm. and 25-30 mm. respectively. The distance between successive Messchaerts i.e. the pitch is 3-6 times the pitch of the main grooves. For keeping the Messchaerts free from bagasse and clean, scrapers with special fingers extended to the bottom of the grooves are fitted below the rollers.

'Chevron' grooves cut longitudinally along the roller grooves have the purpose of assisting the mill to grip the feed better and thereby improve the feed to mill. The helix formed by cutting in the teeth of roller grooves form an angle of 18° with the longitudinal line on the roller and the distance between successive Chevrons is 20-25 cm. Chevrons are cut on the top and feed rollers only. With more positive mill feeding devices the Chevron can be dispensed with.

6.3. Pressures on rollers mill speeds and power for mills

6.3.1. The system of hydraulic pressure exerted on top rollers of mills is so designed as to maintain constant pressure irrespective of the volume of cane or bagasse passing through the mill. In modern mills the pressure is transmitted to the top roller journals from hydropneumatic accumulator by a system of piping conveying oil under high pressure. A typical accumulator is a cylinder containing nitrogen filled in inflated bladder, which gets compressed or dilated when the hydraulic ram on the top of roller journals, is lifted or falls due to the variations in the quantities of cane or bagasse. The accumulators are provided at both the ends of the mills in close proximity to the hydraulic ram and are equipped with indicators of lift which help regulate pressure on mills. The maximum lift of top rollers ranges for 20 mm. to 35 mm. The hydraulic system comprising
accumulators, oil-piping etc. is designed for pressures of 250-300 kg/cm$^2$. Pressures increase towards the end of the length of milling tandem and are highest on the last mill. The total pressure on the projected area of roll journal (length x diameter) should be in the range of 100 to 115 kg/cm$^2$ according to E. Hugot.$^{12}$

6.3.2. Speeds—Higher peripheral speeds exceeding 15 m/min. or more are maintained in Louisiana and some countries in the West, while slow speed of 8-12 m/min. are favoured in some regions. Increasing the speeds is conductive to higher crushing rate but results in fall in extraction efficiency. In Indian industry speeds maintained are usually 8 to 10 m/min. In Hawaii speeds are increased from first to last mill, a practice which runs counter to the method followed in Java and other countries of gradually decreasing mill speeds from first to last mill.$^{13}$ Many mills at present maintain the same speed for all the mills.

6.3.3. Settings—Mill setting implies the openings between the top roller and the two bottom rollers i.e. feed and discharge openings, as also the opening at the trashplate. Proper setting takes into account the
(a) desired rate of crushing,
(b) fibre content of cane,
(c) extraction aimed at,
(d) grooving, and results in smooth operation combined with good performance.

The mill settings are generally calculated following the method given by E. Hugot based on
(a) fibre content of bagasse from each mill,
(b) residual juice in bagasse of each mill.

From a & b volumes and densities of compressed bagasse are arrived at after considering the reabsorption factors for a given set of conditions with respect to cane tonnage to be processed, fibre content, brix of primary juice and method of imbibition. Feed openings are always larger than the discharge openings. The delivery openings are first worked-out and in general.

(a) ratios of feed opening to delivery openings are maintained as 1.7 to 2.2 from last mill to first mill,

(b) ratios of delivery openings of mills at rest to delivery openings in operation termed as safety coefficients have been specified by Hugot.$^{14}$ The trash plate setting involves distances between the top roller and different points on trash plate like toe, plate and heel, and has a great bearing on the smooth working of the mills.

6.3.4. Power for Mills—Mills, with the massive rollers and other heavy duty machinery components consume considerable power and are driven by high power turbines. The various factors which determine the total power required for milling tandem are—

(i) Power for compression of bagasse,

(ii) Power to overcome friction between bagasses and trash plate,
(iii) Power loss in bearings, gears etc.
(iv) Power for intercarriers, under feed rollers etc.

Total power required under normal conditions is 20-30 I.H.P. per t. fibre per hour per mill, installed power being 15-20% higher than actual power requirement. As regards the distribution of power consumed for first mill of Fives Lille Cail C 46 type mill unit Hugot gives 56% for top roll and 22% each for feed and discharge roller, but for later mills considers power distribution as 55% for Top, 10-20% for feed and 25-35% for discharge.

7. OTHER ANCILLARY UNITS

The entire milling station is equipped with other machinery, besides the main mills, for performing different functions like conveying bagasse, juice etc. for carrying out the entire function of extraction. These are as under:

7.1. Intermediate carriers—These steel carriers of the same width as the mills convey the bagasse from the discharge of one mill to the feed side of next mill in succession. The most common types are slat type conveyers, with the steel slats overlapping as in cane carrier. These carriers are driven from top roller and necessarily have linear speeds higher than the peripheral speeds of mills.

Rubber belt conveyers have come into vogue in the last few decades in some countries of the West. The rubber belt passes over two drums, the upper one and the lower one, while the drive is provided to the upper drum. This assembly is light as compared to all steel slat type carrier, and easy to maintain as the wear of belt is much less when it is erected true and the drums are parallel.

In Reunion rubber belt intermediate carriers running at speeds 8-20 times the peripheral speed of the roller (80-140 m/min.) were developed which gave the advantage of thin layer of bagasse over which imbibition can be more effective. According to E. Hugot this system coupled with underfeed roller is extremely useful from the point of view of effective imbibition and mill feeding.

7.2. Juice Strainers

7.2.1. Fine bagasse particles drop from the mill rollers into juice and have to be separated for proper processing of the juice. The bagasse particles dropping from mills are carried by the extracted juice and are known as bagacillo or 'cush cushion' the quantity of which varies from 1 to 10 gms. of dry matter per litre of juice. As this cushion can cause disturbance in the clarification process it has to be separated at the mills by installing screens. Special juice strainers are installed on the mills which separate the bagacillo to be put back on the bagasse leaving first mill. Both the primary and secondary juices need straining.

7.2.2. Formerly elevator type inclined screens, known as cush cushion elevator which consist of perforated brass sheet fixed in frame were quite common. The screen is stationary and cushion separated from the juice fed to screen is constantly removed by moving elevator fitted with rubber scrapers, and dropped into a screw conveyor for being added to the bagasse after first mill. This type of strainer, is troublesome to maintain because of
wear of elevator chains and insanitary conditions generated. It has now been replaced in modern plants.

Yet another type of strainer is the rotary Peck strainer installed above the intercarrier after first mill. Juice is fed in a thin sheet to the screen and screened juice is removed from the tray underneath. The cushion falls on the intercarrier.

7.2.3. Vibrating screens mounted on an inclined frame and located over the first intercarrier are efficient for cushion separation. The screen opening can be 0.5 to 0.8 mm.

7.2.4. The most common form of the strainer employed in modern plants is the Dorr Oliver Stationary D.S.M. Screen. This consists of long prismatic Wedge bars of bronze or stainless steel placed in a circular arc, the distance between two adjacent bars, defined as opening, being 0.7 or 1 mm. for mill juices. A trough located at the top, receiving the mill juice serves to distribute juice by overflow over an arc. The bagacillo flows smoothly over the inclined concave surface and drops on the first intermediate carrier over which the screen is located. Compared to other types of screens this stationary type has the advantage of no moving parts, easy maintenance and trouble-free service. One problem with this type of screen is that the bagacillo falling from the screen on to bagasse blanket is rich in juice and adds good amount of juice to bagasse thereby causing recirculation of juice in milling tandem. This has been successfully overcome in some Indian factories by -

(a) locating the D.S.M. screen by the side of the mills,
(b) Installing a screw conveyer with perforated bottom and juice receiving trough.
(c) allowing the juice-free cushion to drop on first intermediate carrier and,
(d) directing the juice to mixed juice tank.

7.2.5. A perfect solution to this problem of juice rich bagacillo (80-85% moisture 10-12% pol) causing juice recirculation in the milling process is to treat cushion separately for stripping it of juice. This has been successfully achieved in Louisiana and Florida by employing screw press developed by French Oil Mill Machinery Company. Results at St. Mary factory in Louisiana with two stage system consisting of light duty press followed by heavy duty press are encouraging. Before the second stage, maceration was applied and the bagacillo after the press was led to final bagasse going to boiler. This system is reported to have increased the grinding rate by 15% but the extra power for the system, inclusive of light duty and heavy duty press is 625 HP. for crushing rate of 3,700 t.c.d.

7.2.6. It is necessary to develop a less power intensive system than the above for separation of juice from cushion, the quantity of which is bound to be high (19-20% fibre) with greater stress on cane preparation by shredders or fibrizers.

7.3. For application of imbibition, the methods adopted are designed to bring about thorough contact of the imbibition fluids with the bagasse, and require installation of different fittings and equipment. The water is invariably sprayed under pressure, through nozzles fitted to a pipe connected to the delivery of a centrifugal pump. In many plants the imbibition water is passed through a measuring meter installed in the delivery line of the
pump. For greater accuracy in respect of weight of imbibition water, an automatic hot water weighing scale is installed through which the water is passed.

For proper distribution of imbibition juice on bagasse, troughs with wide plates are fitted over the discharge sides of mills such that the juice falls on the bagasse soon after it emerges from the mill. The imbibition juice pump delivers the juice at the centre of the feeding trough from which it flows over an inclined plate in the form of curtain. With steady flow of juice into the trough smooth and uniform flow is ensured with this system.

7.4. Juice tanks and pumps—The Juice collecting under the mills, in troughs is led into stainless steel or copper cylindrical tanks of whirler type connected to pumps. The pumps are of centrifugal, unchokable open impeller type, and adequately sized to allow recirculation of part of juice, either on the mills or in the gutters. The gutters, tanks and pump parts have to be resistant to acidic juice i.e. of copper, stainless steel to minimise wear and prevent stoppages, or loss of juice on account of leaks. These chokeless pumps are not advisable below 100 t. p.hr. crushing according to E. Hugot. Nevertheless these pumps are employed with advantage in Indian factories for handling 50-60 tonnes juice per hour. The pipes for the juices have to be of corrosion resistant material and the previous practice of installing cast iron pipes was abandoned in favour of copper and later stainless steel pipes. Now-a-days P.V.C. or other synthetic material pipes are becoming quite common. The discharge piping must have long radius bends, and should preferably be of larger size than the pump discharge. The pumps at the mills are kept running always, with part of the juice from discharge side being circulated to the mill gutter. A well designed system of chokeless pumps and juice piping operates smoothly in mill house.

The bagacillo flowing along the surface of the screen carries with it good amount of juice both primary and secondary thereby adding to the load of subsequent mills affecting the mill extraction. This is rectified in some factories by locating the D.S.M. screen at right angles to the milling train whereby the bagacillo with juice are received in a screw conveyor with perforated bottom and juice receiving trough, the juice and bagacillo being conveyed to the screened juice receiver and first mill bagasse carrier respectively. Perhaps this problem could be tackled effectively by resorting to two stage screening of juice, the first with 1 mm. opening between bars followed by second screening in the same D.S.M. apparatus with 0.5 or 0.7 mm. opening. Needless to state that proper attention to sanitation by steaming and use of effective biocides will improve effectiveness of the screen, operation. The wedge bars should be of stainless steel or 'everdur' bronze and the juice feed trough as also the screened juice receiver should be of stainless steel both from the point view of minimising corrosion and contamination.

8. PROCESS OF EXTRACTION

8.1.1. Imbibition—In the milling process, the first mill extracts 50-70% of the total juice contained in the prepared cane, the remaining offering resistance to removal from fibre by simple compression in rollers. With a view to extracting the remaining juice it is imperative to resort to 'imbibition' which consists in spraying diluted juice or water on
the bagasse emerging after each mill in the milling tandem. In simple imbibition water alone is applied to bagasse from every mill, but is no longer practised in the industry. The compound imbibition adopted universally involves the application of water only on the bagasse fed to last mill, the juice from this mill being sprayed on the bagasse going to the penultimate mill while juice from the penultimate mill is added at the preceding mill. This recirculation is continued up to the second mill, the juice from which constitutes the secondary juice. This secondary juice when combined with primary juice from first mill is known as mixed juice sent to boiling house for processing. In some milling tandems with five or six mills at times imbibition water is applied at two last mills, the major portion being used at the last mill.

8.1.2. Principles—The main concept underlying the practice of imbibition is to dilute the juice contained in bagasse prior to its squeezing in mill rollers of the second and subsequent mills. System of imbibition for any mill must take following into consideration:

(i) dry moisture free bagasse has the potential to absorb 500-1000% water, while in actual practice the ratio of water to dry bagasse is seldom higher than 250-300%.

(ii) the compressed bagasse as it emerges from the mill can absorb liquid quickly before it expands and absorbs air. Thus the ideal method of imbibition would involve contact of imbibition liquid with bagasse prior to its expansion after milling i.e. at the point of emergence from discharge roll.

(iii) in practice the proper distribution of imbibition fluid over the bagasse layers as also thorough contact of imbibition fluid with lower and upper layers of bagasse over the entire width of the bagasse carrier is very difficult.

(iv) use of hot water of 70°C and above favours higher extraction though it creates difficulties in the feeding of mill compared to cold imbibition. In keeping with this, modern practice is to employ upto 80-85°C hot water. Compound imbibition being an important aspect of the entire process of extraction needs careful planning and in this behalf following point needs emphasis:

The process of imbibition envisages thorough contact of imbibition fluids with the juice adhering to fibres in bagasse which is accomplished by uniform spray of imbibition fluid over the entire blanket of bagasse. In fact bagasse steeped in imbibition juice or water would give higher extraction and this practice known as bath maceration is adopted in some mills of Australia. However bath maceration calls for

(i) Larger distance between mills (10-15 m) compared to standard mills,

(ii) use of different design of conveyers as intermediate carriers in place of slat type conveyers.

Another effective method of application of imbibition is to install trough to receive the emerging bagasse from a mill with a continuous stream of imbibition fluid. This system developed by E. Hugot.19 and known as integral imbibition is compact and effective. It is desirable to apply imbibition water to layer of bagasse from top as well as from below, employing jet spray.
8.1.3. The quantity of water to be used as imbibition depends on mainly the capacity of the evaporator to evaporate the same but the advantages of application of high imbibition have been established in Hawaii, South Africa and Australia where the amount of imbibition water employed varies from 250-300% fibre. Even in Indian industry the level of imbibition established over decades has now been raised from 130-150% to about 200% fibre thanks mainly to the efforts of mills in Tamilnadu. It is necessary to emphasise that real gain in sugar extraction contributed by imbibition is decided by the dilution of juice in bagasse and thus will depend on the thoroughness with which all the bagasse receives imbibition. Recirculation of part of the extracted juice before the same mill in addition to the juice from subsequent mill has been advocated to ensure more efficient contact of juice in bagasse with dilute juice or water. 20

8.1.4. The steam aided imbibition proposed by KSG Doss 21 envisages the combination of steam and hot-water, in such a way that the steam is applied before the compressed bagasse absorbs air on discharge, while water is sprayed in the usual way. A canopy over the spray system is necessary to prevent bagasse from flying away. High pressure hot-water spray from above and underneath the bagasses layer adopted in some factories has yielded positive results as it ensure thorough contact of water with all portions of bagasse.

9. MILL CAPACITIES

The capacity of a mill, expressed as tonnes cane crushed per day or per hour is governed by so many factors the prominent among them are discussed below—

(a) Cane quality—The fibre content of cane influences the grinding capacity in as much as for a given set of conditions with regard to the power supplied, mill setting etc., the maximum amount of fibre mat can pass through the mill will be limited and more or less fixed.

(b) Size of mill and rollers—The quantity of bagasse passing through a mill is directly proportional to the length of the rollers and the square of the diameter of the rollers. Similarly increasing the number of mills of short milling tandems of four mills enhances the capacity for a certain minimum extraction performance.

(c) Cane preparatory devices—The extent of cane preparation exerts profound influence on the capacity of mill in that the finer preparation improves throughput in the same mill. The conventional two sets of knives enhance capacity by 15-20% while combination of shredder and knives effects 25% increase in milling.

(d) Miscellaneous—Modern feeding devices installed on mills, like two roller mills, toothed rollers have substantially contributed to increase in capacity. Similarly separate treatment of crush crush from the juice strainers in French Press as also introduction of this type of press for one more extraction after last mill in Louisiana and Florida have added to the grinding capacity of mill by 13%. 22
For conventional mills the capacity formula proposed by E. Hugot is as under—

\[
A = \frac{0.8 \cdot cn(1 - 0.06nD) LD^2 \sqrt{N}}{f}
\]

where

\(A\) = Mill capacity tonnes cane crushed per hour

\(f\) = Fibre per unit of cane

\(L\) = Length of roller in m.

\(D\) = Diameter of roller in m.

\(n\) = Speed of rollers in r.p.m.

\(N\) = Number of rollers in tandem

\(c\) = Coefficient for preparation

  = 1.15 for two sets of knives

  = 1.25 for two sets of knives followed by Searby type shredder

  = 1.22 for two sets of knives followed by Maxwell shredder

Needless to state that the mill maintenance has a significant role to play in the efficiency and capacity of the mill, while the operation aspect is equally important. In the case of sugar plants established in the past two decades, in conformity with the standard specifications drawn by the Govt. of India, initially the four mills of 760 x 1550 mm. size were installed which could handle 1600-1800 tonnes cane per day. Later on the plant expansion was accompanied by addition of two mills of the same size. In Indian Industry these six mills preceded by set of knives and fibrizer or shredder have been able to crush 3000 tonnes cane per day at a fairly high efficiency level. New feeding devices along with simple additional compressions in two roller mill, have contributed a lot to the mill capacity. Some innovations in this behalf, successfully established in Indian Sugar Industry are described below—

10. MILL FEEDING

Cane preparation coupled with high levels of imbibition render gripping of bagasse extremely difficult and new feeding methods had to be evolved to overcome the mill feeding problem in order to accomplish the beneficial effects of cane preparation and high levels of imbibition (about 200% on fibre), with regard to extraction and capacity. Apart from the quantity of imbibition water, the high temperature of water creates difficulties in cane feeding. Following devices operating in conjunction with the mills or attached to mills ensure positive feeding of prepared cane and bagasse fed to mills.

10.1. Donnelly chute—In the gravity feed system closed feed chute is provided at an angle of 75° to 90° to the horizontal. Since the total pressure of bagasse in the chute is a function of the accumulated bagasse and the area, angle approaching ± 90° and greater height of chute are effective. The inner parts of this chute viz. the side plates have to be very smooth and
are preferably of stainless steel to avoid frictional resistance and for easy flow of bagasse or prepared cane, and the chute has to be somewhat tapered towards the feed end. It is usually provided at the first mill, where cane preparation is fine.

10.2. Underfeed rollers—This is by far the most commonly adopted feeding device in Indian Sugar Industry. The underfeed rollers usually are of cast iron and grooved, with diameters half to two thirds of the mill roller diameter. The drive for these rollers is provided from the mill rollers by pinion or chain. The peripheral speed is about 10% higher than that of the mill to which it is attached. The clearance between the underfeed roller and the mill feed roller has to be minimum preferably 7-10 mm. The merit of this system lies in the fact that the underfeed rollers require low power (5-10 hp.) and can be fitted in the existing mills without much modification in the mills, but helps improve capacity and extraction of mills.

10.3. Continuous pressure feeders—

(i) Originating in Australian Industry, this feeder consists of a pair of rollers mounted ahead of the mill and connected to the mill by closed chute of stainless steel, which has some what more opening towards the mill. The power for drive for these rollers which are provided with grooves is supplied from the mill turbine. These rolls extract good amount of juice reducing the load on the mill and rendering gripping action easy. The speed of these rollers is about 30-70% higher than that of the mill. The heavy duty continuous pressure feeders of this type cannot be installed in the existing mills with 6-7 m. distance between two mills, but they give positive improvement in capacity and extraction as they permit of addition of high imbibition and fine preparation.

(ii) T R P F—In a later development in place of the grooved rollers, toothed rollers came into vogue. Toothed rings are fitted to rollers and are welded with hard faced electrodes for maintaining their condition as their wear affects the performance. The toothed rollers push the bagasse blanket towards the mill and provide more positive feed. The power requirement of toothed rollers is about half that for grooved roller pressure feeder described earlier. The conditions with respect to chutes from pressure feeders to mill are the same as in the case of two roller pressure feeders. Performance of two roller pressure feeders suffers at fibre rates exceeding 25 t/hr. whereas the TRPF works effectively even at higher fibre rates.

In Indian Industry both these systems of pressure feeding of mills have been installed with advantage, the capacity being enhanced by 50-70% with existing mills. These pressure feeders can be installed when the centre distances of mills are larger, but the mills in India are installed with 7-8 m. centre distance and in order to accommodate them, mills have to be suitably shifted.

10.5. A new type of T.R.P.F. developed in India can be fitted with the existing mills with short centre distance. This feeder is installed on the mill chute and requires shorter chutes. The slat type carriers have to be replaced by rake carriers as intermediate carrier. These short space tooth roller pressure feeders have been installed in few factories with good results, expected increase in capacity being 25-50%. The drive for this pressure feeder is provided from the main mill drive system, by means of sprockets and chain.
11. ARcing OF ROLLERS

Arcing of rollers with special electrodes has been found to be extremely useful in improving the gripping action of bagasse and is practised universally. Arcing not only improves feeding but also reduces wear of roller shell and results in gain in capacity by about 10%.

Lotus roll—Work by Egeter in Java as also by Murry and Bullock in Australia has established that during compression, the mixture of fibre and juice is in the 'semi liquid' state, and the entire juice extracted does not get enough escape path. To overcome this phenomenon of reabsorption of juice, which adversely affects extraction, a new type of roller known as 'lotus' roll has been developed. Of cast steel construction, the Lotus roll has circumferential grooves but the surface has perforations arranged in axial rows, each row being connected to a collecting channel built into the shell. The juice channel has its both ends open for discharging the juice. The extracted juice usually trapped in the bagasse blanket finds passage through the perforations, and is led out from the channels. The lotus rolls are installed as top rollers and are reported to have favourable impact on the performance and capacity of the mills; preventing the slipping action at rollers. The holes have to be cleaned often for the roll to function effectively. In conventional mills the juice removal from compressed bagasse is only from feed and discharge rolls but with lotus roll installation, even top roller removes juice from bagasse.27

12. FACTORS INFLUENCING EXTRACTION

The extraction efficiency of a milling tandem depends on many factors as under—

(a) Cane preparation—Fine cane preparation from the point of view of high preparation index has great bearing on the primary extraction as well efficiency of imbibition. High proportion of opened cells should be aimed at and in this context special attention needs to be given to attaining high degree of preparation.

(b) Primary extraction—Primary extraction means juice extraction by dry crushing which is accomplished in a three-roller or five-roller crusher at the head of the mill the former being the most common in Indian industry. High primary extraction by dry crushing in the mill at the head of tandem renders the task of subsequent mills employing imbibition for extraction of maximum possible juice easy, and in effect improves the extraction performance of the mills. Hence the importance of primary extraction, needs to be appreciated by mill operating personnel. In Queensland where heavy imbibition is practised gain in 1% primary extraction results in increase in total extraction of 4 mills by 0.12% in tandem of four mills and 0.1% in 5 mill tandem. The primary extraction is found to vary from 60-80% and with high degree of preparation and controlled feeding a three roller mill should be able to give 70-75% primary extraction. In four mill tandem the influence of high primary extraction cannot be overemphasised. In Australia and Hawaii 80% primary extraction has been recorded in three-roller mill. Regular primary extraction can be estimated following Hugot formula.
(c) **Imbibition**—After primary extraction, imbibition plays a vital role in determining the overall mill extraction for which essential conditions are

(i) thorough mixing of diluted juice with the respective bagasse,

(ii) efficient drainage of the bagasse juice on compression and finally,

(iii) the quantum of water and juice which is recirculated in the system, the latter depending mainly on the water applied.

As regards the quantity of water applied as imbibition, the initial gains with increase in imbibition applied are substantial but later on the gain in extraction diminishes with increase beyond a certain limit which is about 200% - 250% fibre. In view of the energy conservation needs of the Indian factories higher steam requirements at the evaporator station as sequel to higher amount of water used at mills have to be considered. Taking both these factors into account the level of imbibition at mills should be around 200% fibre, which can be considered optimum economic level under Indian conditions.

In some sugar producing regions like, Australia, South Africa, Hawaii imbibition % fibre is maintained at 250-300 with very high mill extraction. In India Tamilnadu factories have recorded gain in sugar recoveries by raising the imbibition level to 200 and above on the basis of percent fibre, as against the conventional practice of 130-150 in Indian industry. Similarly higher temperatures of imbibition water upto 85°C have been found conducive to better mill extraction. Higher quantities of water at high temperature can lead to feeding difficulties at the mills which can be overcome by the recent innovation in feeding devices as also arcing of rollers.

(d) **Hydraulic load**—Since the mean pressure exerted on bagasse passing through a mill is roughly equivalent to the total pressure acting on the area given by the length of roller multiplied by one tenth the diameter of roller, the specific hydraulic pressure (SHP) acting on the bagasse passing through a mill can be calculated by this method i.e. total pressure divided by the product of roller length and one tenth of the roller diameter. The extraction increases directly in proportion to S.H.P. upto a certain limit (25-27 t/dm²) but the gain in extraction with increase in pressure is reduced thereafter. Usual practice in efficient milling is to maintain 24-26 tonnes/dm². S.H.P. at the mills other man the last mill at which pressure is raised to around 27-29 t/dm²; in as much pressure goes on increasing from first to last mill in the interest of higher extraction of juice.

Length of tandem—Increasing the number of mills in a tandem is helpful in improving grinding capacity as also the extraction efficiency. In conventional design of milling tandems, it is common observation that addition of one or two mills is found to increase extraction by 0.5 to 1 unit, on account of the increase in the number of compressions preceded by more stages of imbibition.

Miscellaneous—For the same thickness of bagasse blanket lower speed favours better extraction and reduction in moisure of bagasse while increase in speed has the reverse effect. By increasing throughput of fibre extraction is adversely affected, thanks to imperfect escape of juice from bagasse on account of higher peripheral speed of rollers, as
per common experience with mills which have to handle higher throughput than the theoretical capacity when faced with prospects of more cane supplies to be dealt with in limited period of the crushing campaign.

13. AUTOMATION

(a) Mill extraction and the operational efficiency of mill depend to a considerable extent on the even and full feeding of cane to the mill. To achieve this objective a system of regulation of speed of the cane carriers has been devised. The control system incorporates a sensor consisting of a number of bars, pivoted on shaft mounted over the carrier, the lower ends resting on the layer of cut cane,

(b) the signal from the sensor is transmitted to the variable speed drive of the carrier. This electronic system of control is installed in a number of sugar mills in India. 'Autocane' control system of Edward Engineering Corporation consists of a sensor, a hydraulic motor and control equipment. The sensor consisting of swinging bars, resting on cane blanket sends signal relating to the height of the blanket on the carrier, to the motor driving oil pump. The carrier drive is provided by hydraulic motor, connected to this oil pump; which thus is able to vary the speed of carrier on the basis of cane blanket thickness, with the help of completely mechanical arrangement.

The detectors or sensors are fitted after cane knives or even after shredder, where shredder is installed.

Complete computerisation of mill functioning has been established in Australian Sugar Industry.

14. Mill Construction

14.1. The horizontal three-roller mill accomplishes two compressions and the construction of mills involves undermentioned components:

(a) the side frames in which rollers are fitted, commonly known as 'mill housing' or 'cheeks'.

(b) bearings for rollers,

(c) trash turner plate to guide crushed cane or bagasse from front roller to bagasse or discharge roller.

(d) hydraulic load

(e) system of drive.

Each mill design has its own special characteristics in regard to above factors. In the Farrel mill design the girder bed plate forms integral part of the housing, eliminating the joint between the bed-plate and housing, which is prone to corrosion under action of acidic juice: The top caps which can be removed vertically, are held securely in the housing by horizontal pins. Yet another feature of this design is the swinging side caps
for side rollers which facilitates the job of changing side rolls. The hinged side caps swing outward and support the roller removed from the housing. Farrel mills are fitted with rubber belt carriers which are claimed to be more durable, easy for maintenance and cleaner as compared to conventional steel slat type intercarriers.

The top angle of the triangle formed by joining the axes of three rollers usually lies between 70°–84°. Reduction of this angle is usually aimed at for reducing the width of trash plate and consequently the friction of trashplate. Smallest angle of 67° is maintained in one design of Fives Lille-Cail by fitting alternate pinions. Later development in the design of Fives mills is aimed at maintaining constant ratio between feed and discharge openings. In the conventional designs of symmetrical housing this ratio is subject to changes according to the mill feed which is never constant but varies frequently quite often. 'Fives' have, in this design, provided at the top a cap which pivots about an axis on the delivery side of the mill. The hydraulic plunger is located on the feed side. This arrangement allows the ratio of around two between feed and delivery openings to be maintained. In this constant ratio design the top roller does not move in vertical guide.

14.2. Size of mills—The specifications for sugar plants for Indian Industries drawn by the Government of India stipulated Standard size of 765 x 1525 mm. for new sugar plants in the early sixties. Accordingly a number of new plants with four mills of 765 x 1525 mm. size were set, for a crushing capacity of 1250 tcd. Some of these plants have been crushing at the rate of 1600-1800 tcd. and after addition of two more mills of the same size have been able to handle 3000-3200 t.c.d. The plants which will be set up henceforth in accordance with recent standard specifications will be equipped with 4 mills of 850 mm. x 1700 mm. size which can be expanded by addition of one similar mill for attaining crushing rate of 3,500 t.c.d. In this connection it needs to be pointed out that the capacities of mills in India have been expanded in many plants by—

(a) improving cane preparation by installation of Shredder or fibrizer,

(b) installing mill feeding devices like TRPF or Feeding rollers, to existing milling tandems.

The largest size of mill reported in literature is from Australia of 1375 mm. dia. x 2750 mm. length, equipped with two rollers of the same size for pressure feeding, and one underfeed roll of 1300 mm. dia. The drive for the mill is provided by two single stage turbines with intermediate gear boxes and low speed gearings, while the pinions are located adjacent to low speed gearing. Each roller weights 42 t. and the underfeed roll weights 38t. The design of the mills follows 'Squier' frame and bronze bearing are fitted for reliability and lower cost. The large size necessitated adaptation of some concepts regarding drive from the established designs developed in mining and paper industries.

14.3. Roller bearings—Use of roller bearings in place of conventional bronze bearings offers certain advantages and these have been fitted in some sugar mills. The roller bearings by reducing friction losses, bring about saving in power consumed in mills, besides eliminating the water cooling system associated with brass bearings. Properly designed roller bearings will also bring down wear on shaft journals. In Indian Industry, some of the mills of 625 x 1250 mm. size manufactured by G.H.H., set up in fifties were fitted with
roller bearings. Despite the advantages in respect of power savings roller bearings have not been adopted in a big way. The following points need special attention in connection with roller bearings—

(a) The bearings should be suitable for heavy loads on the mills,

(b) choice of proper lubricants

(c) the bearings have to be properly sealed and protected from ingress of juice or dirt which can seriously affect the functioning and life of bearings.

14.4. Electric drive for mills—A.C. motor drive for mills was introduced in Cuba while in Java D.C. was used some six decades back. The following systems of electric drive are adopted in Industry—

(i) variable frequency A.C. drive,

(ii) commutator motors,

(iii) Ward-leonard D.C. drive

(iv) Thyrister controlled D.C. drive

Choice of suitable system is governed by undermentioned considerations:

(i) the mills operate at constant torque,

(ii) speed variations of 50-100% of maximum speed of mill have to be provided,

(iii) power for overload for short periods has to be taken care of—

Out of the different systems of electric drive the thyrister controlled D.C. drive is considered suitable for mills since each mill can be equipped with separate motor. The advantages of this system of drive are—

(i) no need to install steam pipes, valves, pipejoints etc.,

(ii) it is easy to ascertain power consumed by each mill,

(iii) speed variations of individual mill are easy,

(iv) operation and maintenance are simple.

As against this the main disadvantages are—

(i) higher capital cost,

(ii) additional stages of transformation of energy viz.,

(a) conversion of mechanical energy into electric energy, at the alternator and,

(b) transformation of electric energy into mechanical energy for mill operation, as compared to direct turbine drive. It thus would be more appropriate for factories with boilers operating at high pressures e.g. exceeding 30-40 kg/cm$^2$ to install electric drive for mills as has been done at Mysore Paper Mills Ltd. where the high pressure boilers and suitable turbine have been in operation. For factories generating electric power from low pressure steam below 30 kg/cm$^2$ total energy balance may not be in favour of this system on electric drive.
14.5. Hydraulic drive—Hydraulic drive for motive power has already been in use in sugar industry for cane carrier, crystallisers, centrifugals but for mills this system has been introduced only in recent years in Cuba and Mauritius. The system of hydraulic drive for mills involves - a. powerpack consisting of a motor driven positive displacement variable output hydraulic pump, oil tank, oil cooler. The power pack is connected to a hydraulic motor and gear-unit which is fitted to roller shaft. Speed of mill can be varied from 0-6 rpm. by altering the output of hydraulic pump. The advantages of this system are

(a) complex heavy gears for reducing speed from say 5000 rpm. in the case of turbines to 3-5 rpm. are eliminated.

(b) space occupied is small compared to conventional turbine drive system. It is claimed that energy consumption is less as compared to the conventional system. However more data on practical observations of the operation of the units installed needs to be collected to determine the prospects of the hydraulic drive for mills.

15. MILL JUICE CHARACTERISTICS

The first mill extracts high purity juice and the brixes as also the purities of juices go on decreasing from first to last mill. The imbibition process and repeated pressings bring about greater extraction of nonsugars as cane passes from first to last mill, as shown by increase in organic nonsugars colloids, wax, phosphate as also total ash from primary juice to mixed juice. The front roller extracts nearly 75% of the total juice extracted by a mill after imbibition, while the remaining 25% is extracted at the discharge roller, the reason being that the bagasse treated with imbibition liquid, parts with superficial imbibition liquid in the first compression, which is of lower brix as compared to juice from mill delivery side, which extracts part of juice contained in inner portions. On the other hand the pol percent of bagasse leaving the mill is lower than the pol of discharge roller juice. Thus the final bagasse pol will be lower than that of last expressed juice of a normally operating mill From the first mill this ratio of pol of bagasse to that of discharge roller juice goes on decreasing to the last mill, and generally it is of the order of 0.7.
REFERENCES

5. Ibid p. 69.
6. Ibid p. 70.
15. Ibid p. 235.
1. The process of diffusion was first introduced in the nineteenth century for extraction of juice from sugarbeet in Europe. In cane sugar industry, many batch diffusion plants consisting of battery of vessels were set up in Egypt, Spain and other sugar producing regions but except in Egypt these met with failure. With the introduction of continuous diffusion in the European beet sugar Industry after second world war, interest in application of the same in cane sugar plants was revived, in as much as continuous diffusers offered many advantages in respect of simplicity of operation and efficiency over the batch diffusion batteries which they replaced. In milling of sugarcane, extraction involves use of massive heavy rollers working under very high pressure, which calls for very high power consumption whereas continuous diffusion is low power consuming and expected to give high extraction performance.

2. PROCESS OF DIFFUSION

When two solutions of different concentrations are either in contact with each other or are separated by a permeable membrane, crystalloids from solution of higher concentration pass into that of lower concentration by osmosis. This phenomenon is known as diffusion. In the case of sugarbeet, the cell wall serves as membrane through which the sucrose passes from the juice contained in beet to water or dilute juice, which is of lower concentration than the beet juice.

In sugar beet industry, diffusion of sucrose through the cell walls, into the water results in extraction of juice which is of high purity on account of the higher rate of diffusion of sucrose than the organic and other inorganic impurities, and the equipment design takes into account the necessity to move the sugarbeet fine pieces (cossettes) in the apparatus such that by the time they leave the diffuser, they are exhausted i.e. most of the sucrose has been transferred to the liquid from the sliced beet.

The sugarcane plant comprises hard portion on the exterior, known as rind as well as nodes, and soft interior which is rich in juice. Maximum juice is stored in the soft tissues and this juice can be easily extracted as the thin walled cells of the stalk can be ruptured and juice released therefrom without much difficulty. The cells surrounding the fibrovascular bundles, and those in the vicinity of the hard rind or nodes being tough in nature resist disintegration. Even with high degree of preparation, with the help of knives and shredders the percentage of cells opened does not exceed 90-92% due to the tough nature of these juice containing cells. From the juicerich thin walled parenchyma cells, after disintegration, juice can be easily extracted by lixiviation or displacement, while the juice from the rind and tough cells is difficult to recover. The unbroken cells are killed by heat whereby the cell wall becomes semipermeable membrane through which molecules of sucrose and other compounds pass into surrounding liquid phase. Heat and repeated contact of thin juice are thus essential to extract maximum cane juice in diffusion. Light squeezing of bagasse after thin juice or water is sprayed on it helps this process. In industrial operation continuous counter current extraction is brought about
by repeated and through contact of bagasse with juice of progressively decreasing concentration. In the case of sugarcane juice extraction by this process, the cells are ruptured and contrary to beet juice extraction, the sucrose transfer is mainly by lixiviation of broken cells than by osmosis which accounts for extremely small percentage of sucrose extracted. In a continuous process of diffusion, extraction of sucrose is effected in a counter current system, wherein the cane or bagasse flow is maintained in the reverse direction to the passage of water. Thus the sugar rich juice of diffuser comes in contact with the fresh feed of cane or bagasse while the exhausted bagasse meets hot water in continuous operation.

3. TYPES OF DIFFUSERS

3.1. The diffusers are preceded by cane preparatory devices, for disintegrating cane, the degree of preparation depending on the design features of particular diffuser. Mainly the diffusers are of two types viz.

(i) sugarcane diffusers which handle the entire disintegrated cane and

(ii) bagasse diffusers for which the bagasse after primary extraction in a mill constitutes the feed.

In both these types the dripwet bagasse emerging from the diffusers contains high moisture 80-85% which has to be brought down to 48-50% in order to render it suitable for feeding the boilers as fuel. This is accomplished in most installations by conventional three roller mills, usually one or two mills being installed for this purpose. In 'Saturne' diffuser a special device helps reduce partially moisture of wet bagasse, before the same is fed to mill for removing the remaining water. As the liquid from wet diffuser bagasse is essentially dilute juice of 2°-3° Bx. the juice from the dewatering mills is sent back to the diffuser.

In counter current system of diffusion the bagasse must come into contact with juices of decreasing brix and two systems are employed for ensuring thorough contact of juice contained in bagasse with juice of lower brix, one is the percolation and other is maceration.

3.2. In the design based on percolation, juice of decreasing brix is sprayed on the layers of cane or bagasse advancing on perforated grid or screen; The juice in this case has to come into contact with every particle of cane or bagasse which calls for

(a) even distribution of juice on the layers of bagasse

(b) proper penetration of juice, through the entire bagasse mat without channelling

(c) optimum time of contact of juice with the bagasse or cane, for attaining the desired degree of extraction as also the required throughput.

The cane preparation must therefore be such that the rate of percolation and its effectiveness are ensured. Too fine preparation can lead to low percolation rate through compact layers while coarse preparation will result in inefficient extraction. It is thus necessary to conform to the standards of cane preparation in regard to size regularity and
degree of fineness, prescribed for each design of the diffuser. The juice from dewatering mills, operating in conjunction with diffusers involving percolation principle, has to be clarified before being circulated in the system, as otherwise it would impede percolation through bagasse layers.

3.3. In the technique of maceration the entire cane or bagasse is conveyed through juice with brixes of decreasing order whereby the bagasse is immersed for short duration in the bath of macerating liquid. This ensures thorough contact of bagasse with juice and every particle of bagasse is surrounded by macerating liquid, there being no chances of channelling of any portion of bagasse bypassing the extraction process. In this case too the standards of cane preparation have to be adhered to for ensuring proper extraction, as well as throughput.

3.4. Conditions of operation—As against the milling wherein the bagasse or prepared cane along with juice remain in the system for few minutes, in diffuser the retention of the same would be 40-150 minutes. Conditions maintained for optimum results in diffusers are as under—

(i) temperature of 70°-75°C is maintained to kill the juice containing cells for facilitating lixiviation. This helps maintain sanitation which is of vital importance in view of longer juice and fibre residence in the system.

(ii) The system must operate at the optimum rate of throughput with marginal variation so as to maintain the desired retention time since longer retention would result in distraction of sugars or extraction of undesirable impurities.

(iii) frequent or long duration stoppages are harmful as the diffuser cannot be liquidated or filled within a short time. It is thus important to maintain a steady and regular operation of the process.

(iv) Parameters of operation of a particular type of diffuser with respect to pH, temperature and time of retention have to be strictly adhered to for obtaining the desired results. Failure to observe these operating parameters results in either decomposition of sugars or extraction of undesirable non-sugars.

3.5. Cane and bagasse diffusers—The structure of sugarcane is heterogenous in that the cane stalk consists of three parts, the outermost hard rind, soft tissues and fibro-vascular bundles. The soft portion contains the juice rich cells from which juice can be easily extracted while the juice from thick walled cells in contact with fibrovascular bundles cannot be obtained without applying heavy pressure and washing. The thin walled juice rich cells, when ruptured part with sugar rich juice by simple squeezing as in primary extraction in milling or by washing but the tightly held juice in the fibrovascular tissues cannot be easily recovered and disintegration of the cells containing the same also offers resistance. Extraction of the latter is possible only with repeated washing in multiple stage countercurrent operation, or repeated squeezing and imbibition as in mill.

There are two types of diffusers (a) those handling entire cane, (b) diffusers for which the bagasse after primary milling forms the feed. For cane diffusers the cane preparation has to be thorough with preparation index of 90, requiring efficient shredding and disintegrating machines. Bagasse diffusers can work well when
(i) P.I. is 60-70,
(ii) primary extraction is 65 and above.

For processing sugarcane of 13% sucrose with target of 96% mill extraction bagasse diffuser in conjunction with primary milling will extract sucrose as follows—

(i) Total sucrose to be extracted 12.48% cane
(ii) Sucrose recovered in primary milling: 8.45% cane
(tit) Sucrose recovered in diffuser 4.03% cane.

Under above conditions the cane diffuser will have to recover the entire 12.48% sugar in cane. Cane diffusion will thus involve more stages of juice circulation and washing as compared to bagasse diffuser and more intense cane preparation. Though the juice passing through a bagasse diffuser is 30-40% that through a cane diffuser, the quantity of fibre handled by both the systems is the same. In both the types, the common features are—

(i) discharge of drip wet bagasse,
(ii) dewatering of bagasse from diffuser and
(iii) putting back into diffuser, the low brix juice from dewatering devices.

3.6. Salient features of operation—Considerable amount of investigational work has been conducted on the theoretical as well as practical aspects of cane diffusion as also the operations connected with various designs that have been developed for the same in the past three decades. Modern continuous cane diffusion employs the principle of counter current extraction of sucrose by intimate contact of thin juice with bagasse which flows continuously through the diffuser. Two methods of accomplishing this objective adopted in different designs of diffusers are—

(a) percolation of thin juice through layer of bagasse or prepared cane
(b) immersion of bagasse in juice, or the maceration of bagasse.

In percolation type units, the advancing bagasse is repeatedly sprayed with juice of progressively decreasing brix and it is important that every particle of bagasse is brought into contact with the juice at every stage of extraction with application of juice. Similarly every drop of juice flowing by gravity should penetrate the bagasse mat and pass through the entire layer into receiving trough. Thus for efficient extraction great stress is to be laid on following conditions:

(i) cane preparation should be such that neither too fine nor too coarse bagasse is fed to the diffuser since fine bagasse resulting in compaction will impede penetration while coarse bagasse will not allow proper lixiviation of all the fibre. Moreover fine preparation can have adverse effect on throughput.

(ii) The thin juice before introduction into percolation type diffusers has to be heated and clarified as otherwise the nonsugar impurities in suspension will clog the interstices in bagasse thereby impeding penetration. Preheating and liming the juice to be
circulated is essential in the context of maintaining the temperature and higher pH (about 6.2 to 6.5) in the diffuser to prevent microbial growth and sucrose destruction respectively.

(iii) In maceration or immersion type diffusers the entire bagasse passes through a bath of thin juice which is maintained at high temperature. In this case too the cane preparation should aim at furnishing bagasse feed of neither coarse nor fine pieces. In such design the bagasse and juice must be rapidly displaced and move at the desired rate without any stagnant pockets being formed. Longer contact of juice with bagasse than required for proper extraction leads to extraction of undesirable impurities as well as decomposition of sucrose both of which are detrimental to the overall recovery of sugar from juice.5

Whichever type of diffusion process may be adopted cine common feature with diffusion is discharge of dripwet bagasse of about 85% moisture which has to be dewatered so as to render it fit for combustion in boiler.

4. DESCRIPTION OF DIFFERENT DESIGNS

In the sixties, after continuous diffusion of beet had been well established, application of this system to cane sugar industry caught the imagination of the research workers and machinery manufacturers. In consequence a number of diffuser designs were developed, and introduced in different cane-sugar producing regions. Some widely accepted designs are discussed below:

4.1. D.D.S. Diffuser—Developed by Danish firm engaged in beet sugar and sugar machinery manufacture by name De Danske Sukker fabrikkar, this bagasse diffuser is designed on two broad principles, one : the diffusion process takes place at the natural pH of juice (5.2 - 5.6) without any alkali addition-two : flow of bagasse through macerating bath of dilute juice of gradually decreasing concentration, accompanied by repeated light squeezing ensures thorough extraction. The pH of operation being in the acidic range of 5-6 the equipment is made of stainless steel. In milling the bagasse is soaked in imbibition water or dilute juice and later squeezed in mills 3 to 5 times depending on the number of mills in the tandem. In D.D.S. diffuser similar effect is accomplished by the conveying of bagasse upwards through a sloping diffuser, wherein the intermeshing two scrolls bring about the repeated light squeezing of the bagasse soaked in juice. The temperature of the juice is maintained at 65° - 75°C; no addition of lime being practised.

4.1.2. Construction—The D.D.S. diffuser is an 'co' shaped stainless steel vessel, having two shafts each fitted with helical scroll provided with perforated sheet flights. These scrolls rotate in opposite direction and carry the bagasse upward in the diffuser which has an inclination of 4°-7° with the horizontal while at the upper end of the diffuser, the double vertical screw conveyer lifts the wet bagasse which drops on the conveyer going to dewatering mills. The helices of two scrolls intermesh in such a way as to maintain space of 0.5 pitch between them and the teeth attached to their periphery ensure displacement of wet bagasse on the shafts of scrolls, and avoid any bagasse accumulation in the vessel.
The two scrolls driven by D.C. motors and reduction gears, revolve at 2-2.5 rpm. in such a way that when one scroll is moving faster by say 5%, the speed of the other is reduced by 5%, after some predetermined interval, the one that was slow gains speed while the other moves slower. Controller is installed to automatically regulate these variations of speed of both the scrolls at regular intervals. This alternate gain and loss of speed of the scrolls, results in oscillation, whereby the wet bagasse is squeezed between the fittings of two scrolls approaching each other and receding from one another. The squeezing action releases the juice from wet bagasse, which again absorbs thinner juice and gets soaked during its passage upwards. This alternate squeezing and soaking takes place 20-30 times throughout the passage of mass from one end to the other altering the fibre-content of wet diffuser bagasse between 13 and 25%, which constitutes the principal feature of this design contributing to high extraction.

The residence time of bagasse in diffuser is 30-40 minutes while in the case of juice even though for a major portion, the time may be about 20 minutes, certain portions of juice are absorbed at the discharge end of bagasse and are recirculated in the diffuser 3 times being removed as diffuser juice.

The diffuser is provided with steam jacket for heating the mass inside with exhaust steam and maintain temperature thereof at 65°-75°C. The extreme ends of the diffuser are not covered by steam jackets from underneath whereby the bagasse emerging from the diffuser is cooled to some extent. The temperature controller regulates the steam for maintaining the desired temperature. The diffuser tank is of m.s. construction but clad with stainless steel while the shafts and helices are of stainless steel. The connected power is 1.8—2 KW/tch while in practice the actual load may be 50-60% of the connected load.

4.1.3. Controls and instrumentation—

(a) Controllers have been provided as under—

(i) for varying the speeds of the two scrolls in rotation in relation to each other by \(\pm 5\%\)

(ii) for maintaining imbibition/bagasse ratio i.e. for regulating the quantity of water fed to diffuser on the basis of bagasse feed.

(iii) for maintaining the desired temperatures in different hatches of the diffuser.

(iv) for regulating the flow of diffuser juice by controlling the level of juice at the lower end-four meters from the screen.

(b) Instrumentation includes—

(i) continuous bagasse weigher installed over belt conveyor employed for transporting bagasse from mill to the bagasse feed-end.

(ii) recorders for temperatures in the compartments of diffuser; bagasse weights and incoming imbibition water.

(iii) indicators for voltage and current,

(iv) switches for speed alteration of scrolls.
4.1. Operating conditions—

1. The cane preparation by two sets of knives suits this diffuser and too fine disintegration by shredder etc., does not give any advantages.

2. Primary extraction in milling has to be about 65-70% and low primary extraction increases load on the diffuser affecting extraction, since the diffuser is given the task of extracting 25-30% sugar in cane loss of primary extraction by 5% would result in 20-25% extra work for diffuser.

3. Optimum draft is about 95-100. Within certain limits of ± 10% the sugar loss in bagasse is inversely proportional to draft.

4. reducing retention time below the optimum of 30-40 min. results in inefficient extraction, while high residence time will give high extraction of non-sugar as well as inversion of sucrose.

5. pH of juice in the diffuser varies from 5.2 to 5.6. Lime addition to diffuser or defecation of press water i.e. dilute juice from dewatering of diffuser bagasse are not favoured by the manufacturers.

4.2. De Smet diffuser—

4.2.1. This diffuser operating on percolation principle is manufactured for cane as well as bagasse diffusion. The bagasse diffuser T.S. type is of 30 m. length and is provided with 11 washers while the cane diffuser TN type is 35m. long and has 17 washers. Even the width of T.N. type diffuser is more viz. 80 mm./tc/hr. as against 28 mm. for the bagasse diffuser. The major component of the diffuser is a moving horizontal conveyer of grid and screen type, supporting the bed of bagasse. The conveyer is housed in a mild steel rectangular tank. Below the conveyer are mounted a number of hoppers, with sloping bottoms, to receive the juice from the bagasse layers over the screens. Each hopper being connected to a separate pump. Each pump returns the juice to the distributor above the grid conveyer located over the preceding juice tray. In this way the juice moves backwards passing from one tray to the preceding one, from the bagasse discharge end to the feed end. The last distributor at the bagasse discharge end receives hot water and the diffusion juice is collected in a special tank near the bagasse feed end. The juice is evenly sprayed over the advancing bagasse fed by overflowing troughs extending over the entire width of bagasse. The distributors are located over the hoppers, receiving juices from the distributors through the bed of bagasse. Thus a real countercurrent extraction takes place, wherein the brix of juice gradually increases from bagasse discharge end to feed end the bagasse gets exhausted while advancing to discharge end.

The final rich juice is pumped through heater to feed hopper receiving bagasse which is led through a long tube, widened at the end and fed on to diffuser to ensure even distribution of bagasse. A part of this juice is straight led to boiling house through a branch connection from the pipe delivering juice to bagasse hopper. The portion of juice fed to bagasse hopper serves to entrain the bagasse and feed it to the bagasse conveyer. This in effect amounts to recirculation of some heated juice which will, besides scalding bagasse, assist conveying of bagasse and improvement in extraction. At the discharge
end of the conveyor the exhausted wet bagasse is dropped by a tumbler into an elevator for transporting it to dewatering mills. The thickness of bagasse layer is adjustable from 1 to 1.7 m. for bagasse diffuser and about 0.7 to 1.6 m. in cane diffuser which has 10% more length than the former.

The drive for 15-18 pumps is provided in a special manner. Three pumps, mounted on a common shaft in one housing have a common electric motor drive. This way groups of three pumps are installed, the total number being 9,12,15 or 18, for circulating the juice. One of the three pumps passes the juice through heater for maintaining the desired temperature in the diffuser. Fresh imbibition water is sprayed on the bagasse mat at the discharge end. This way as bagasse travels from feed to discharge end it is sprayed with juice of decreasing brix and finally with water, thereby getting exhausted in a gradual manner.

4.2.2. Regulation and control

(a) Cane or bagasse 'passes over weighing belt before being fed to the diffuser. A control mechanism on the basis of this weight regulates a. imbibition water b. flow of juice recirculated and thereby the draft.

(b) Temperature controllers are provided for scalding juice.

(c) The conveyor supporting the bagasse is fitted with variable speed drive for maintaining apron speed at the required rate varying from 0.2 to 1m. per minute.

(d) Thickness of cane or bagasse layer can be adjusted. On a central control panel are mounted controls, regulators besides indicators and recorders for various operating parameters like temperatures, pressures, rate of flow, flow, diffuser load etc.

4.2.3. Operation—

(1) Cane preparation—For bagasse diffuser i.e. T.S. type the cane is disintegrated by two sets of knives and crushed in a three roller mill. The bagasse from the mill is continuously transported to the diffuser by belt conveyers.

For TN type combination of two sets of knives and shredder is considered essential.

In both the systems good preparation of cane has a great bearing on the extraction efficiency. But while ensuring good preparation care has to be taken to see that proportion of fines is not high enough to retard percolation rate through bed of prepared cane or bagasse.

(2) Layer thickness—Proper soaking of bagasse with juice will to a large extent depend on the thickness of the bagasse or cane layer on the conveyor. With thickness of bed below 1 meter the time of contact of the diffusion juice with bagasse tissues will be inadequate for sugar extraction, while with a mat exceeding 1.7 m. thickness the bottom layers of the bagasse will not be washed properly for extraction of sugar. The rate of percolation of juice through bagasse layer is 8.5 - 10 cm/sec. Optimum heights of layers are 1.2 - 1.5 and 0.75 - 1.2m for T.S. & TN type diffusers respectively.

(3) pH—It is desirable to maintain pH between 6 to 7 during the operation to avoid
inversion, due to low pH as also the decomposition of pentosans and reducing sugars caused by alkaline condition. The thin juice from dewatering mills with about 2° - 3° brix is limed to pH 8, heated to 80° - 85°C and sent to subider with a settling area of 0.185 m²/tch after addition of flocculant. The resulting clear juice when added to hopper juice at the tail end helps maintain optimum pH in the process of lixiviation. Moreover the elimination of suspended and other impurities from the low brix mill juice improves its ability of penetration through bagasse bed.

(4) Time and temperature—For bagasse diffusion in TS type diffusers the time of residence is about 50 minutes for bagasse, while the juice retention period is 20-30 minutes.

In the case of TN type diffuser the time of residence for bagasse and juice is about 70 min. and 35-40 minutes respectively.

The temperature of 65° - 75°C is maintained along the diffuser by heating the hopper juices, and by initial scalding at 70°C.

4.2.4. Miscellaneous—

(a) The installed power for T.S. diffuser varies from 1.8 to 2.3 hp/tch, higher power being installed per tch. for diffusers of low capacities, while the actual power consumption is lower by 10-15% than the installed power.

(b) The conveyor for bagasse or cane has a slope of about 2% whereby the advancing bagasse is made to rise slightly on this slope, to ensure proper traversing of juice through bagasse bed.

(c) The construction of diffuser permits—

(i) regulation of height of bagasse bed

(ii) regulation of speed of conveyer,

(iii) sampling of juices from individual hopper, for checking performance,

(IV) observation of passage of material.

4.3. B.M.A. Egyptian diffuser—

4.3.1. Like the De Smet diffuser this too works on percolation principle, in a continuous countercurrent diffusion system, main difference between the two being the construction for conveying bagasse. In De Smet plant the conveyor supporting the cane or bagasse is moving while in the B.M.A. design for bagasse diffusion, the conveyor is a fixed plate with perforations of 10 mm. dia. conical in shape, the bagasse being pushed by scrapers over this plate. The conveyor of the bagasse consists of four strands of endless chain fitted with metal slats with equal spacing, fixed to it, travelling at the rate of 0.7 - 1.5 m. per minute. This horizontal diffuser is a covered vessel with vents. A U shaped trough at the bottom is divided into a number of chambers to receive diffuser juices of varying concentrations while juice distribution troughs are located above the bagasse mat. The juices from the bottom chambers are heated in heaters and circulated by chokeless pumps
in a countercurrent flow to the passage of bagasse, the total number of pumps being 5 to 7. The bagasse bed can be of about 1.7 m. in height. The juice distributors in relation to juice collecting tanks are so positioned as to ensure that the bagasse is drained before receiving next juice shower and that juice sprayed is collected in the tank below.

4.3.2. The water added at the end together with the juice of low concentration from the dewatering mills get enriched progressively with sugar until it reaches the last tank at the inlet of the diffuser. This juice is heated in a juice heater and sprayed on the bagasse entering the diffuser for raising the temperature of the same to about 70°C, excess being sent to boiling house along with primary juice for clarification. The bagasse before leaving the diffuser is drained of its excess water by light pressing under a large roller and then sent to dewatering mills for bringing down the moisture content from 75-80% to the acceptable level of 48-50%. The thin juice from the dewatering mill is screened, heated to 90°C and limed to pH of 8.5 or above and sent to a small subsider. The thin clear juice from the subsider is returned to the diffuser for spraying on to the bagasse.

The residence time of bagasse in the diffuser is about 40 min. while that for juice is 20-24 min. The bagasse bed thickness can be adjusted by varying the speed of the scrapers. Cane preparation before primary mill should be effected by two sets of knives and shredder installation is not advocated as finer preparation leads to decrease in the rate of percolation of diffuser juices through bagasse bed. The pH inside the diffuser is maintained at 6-6.5 and temperature around 65°C-75°C. The power required is reported to be 1.2-1.5 hp/tch, while steam consumption is 12-13% cane.

4.4. Silver ring diffuser—

4.4.1. This cylindrical type diffuser works on the same principle as the De Smet diffuser, the major difference being in the extent of cane preparation which is very fine and is sought to be achieved by special disintegrating machines, while the extraction is brought about by percolation principle. This diffuser is designed to handle cane. The equipment employed is described below.

4.4.2. Cane preparation—

First stage in cane preparation consists in passing it through a set of knives. This partially cut cane passes over magnetic separator for removal of iron pieces for protecting the subsequent equipment, viz. the buster and fibrizer, which has vital significance for machine harvested cane.

The buster receiving the lightly knifed cane, is essentially a hammer mill revolving at 1150 r.p.m. The feed to the buster is arranged through two rollers with variable speed mechanism but rotating at low speed of about 120 r.p.m. The rollers fitted with about 20 mm. dia pins of 100 mm. length, regulate the cane feed into the buster. The heavy duty hammers of the buster tear the cane, while swinging and the fine pieces of about 100-150 mm. length fall through the grille made of horizontal anvil bars on to an elevator. Lime is added to this coarsely shredded cane.

The elevator leads the shredded cane to another hammer mill known as fibrizer. A smooth roller with fixed speed and similar in construction to the upper feed roller of
butter, feeds this cane to the top of the fibrizer, which rotates at the same rate as butter i.e. 1150 r.p.m. Under impact of revolving hammers the cane scraped against a grid of toothed cylindrical plate, is shred into long pieces of separate fibres. The finely prepared cane dropping on conveyer is fed to the diffuser. Fine preparation of cane is of paramount importance for achieving high performance with this diffuser.

4.4.3. Diffuser—The Silver Ring diffuser is a ring shaped vessel with perforated bottom. The diffuser rotates at about 0-3 r.p.m. being fitted with system of hydraulic drive. The moving vessel, consists of two concentric cylinders, the inner one being of about 60% smaller diameter than the outer one. The bottom plates of the diffuser, provided with 12 mm. dia holes facilitate drainage of juice into juice receiving tanks located below the diffuser vessel. In all 20 such receivers are arranged at equal distances from each other along the periphery of the moving annular vessel. In essence the diffuser comprises three concentric chambers—

(a) the moving assembly supporting the cane,

(b) the stationary ring consisting of juice receiving chambers,

(c) The stationary section of juice distribution troughs.

The moving assembly slides along the stationary sections with liquid tight joint. The annular moving section is supported on wheels running on circular rails and it is provided with hydraulic drive. A small portion of the moving ring of about 15°, is always empty and separates the incoming feed from the exit of exhausted bagasse. Three pairs of vertical screw conveyors installed close to each other, with two screws of each pair running in opposite direction, elevate the wet bagasse and drop it into horizontal screw conveyor for conveying it to dewatering device via a belt conveyor. The receiving troughs are inclined towards outer periphery and are connected to separate pumps.

4.4.4. Operation—As the prepared cane from the fibrizer is fed into the first compartment of the diffuser it is distributed by special device. This meets the spray of recirculated juice heated to 85°C whereby the temperature of the feed is raised, as in the case of De Smet diffuser, to about 70°-75°C. The counter current extraction involves thorough contact of moving bagasse with juices of progressively decreasing concentration sprayed by distributors. The juice percolating through the bed, is received in the trough below and pumped to the distribution box above the diffuser, located 45° ahead of the receiving tray. The thickness of the bagasse bed is about 1.5 - 1.75m. while the temperature throughout the operation is maintained at 70° - 75°C by reheating the circulating thin juices through heaters to 80° - 85°C. The pH in the diffuser is about 6.5 while the pH of juice leaving the diffuser is maintained at 7.0 by addition of lime before and after the fibrizer as also the recirculation of the juice through the cane mat at the entry bringing about proper mixing of lime with the juice. The residence time of cane and bagasse in the diffuser is 60 minutes while the juice remains in the system for 20 minutes. The high brix juice from the diffuser is sent to boiling house as clarified juice, thus eliminating the clarification of raw juice, in factories following lime defecation.

The wet hot bagasse containing about 85% moisture can be dewatered in one of the following equipments.
(a) special cone press, or
(b) French press or
(c) two mills for bringing down the moisture to normal level for combustion in boiler.

Out of the above dewatering equipment the silver cone press holds promise in future as it can reduce the bagasse moisture to 45%.

The thin juice from dewatering unit is twice screened, heated to about 80°C, limed and allowed to settle in clarifier. The clarified juice is sent to the last but one stage in the diffuser towards the exhausted bagasse end, while the settled mud goes to rotary vacuum filter.

4.4.5 Miscellaneous—The diffuser installation, without the dewatering unit requires about 15 H.P./tch. The material of construction of the Silver ring diffuser is stainless steel even though the pH maintained is around 6.5 by use of lime. The flow of cane to the unit, and various temperatures are automatically controlled.

4.5 Saturne diffuser—

4.5.1. The design of this vertical wheel type diffuser employs principle of complete maceration or immersion of bagasse, coupled with addition of lime. The diffuser comprises (a) fixed circular annular container having rectangular cross section of 12 m. external diameter and 9 m. internal diameter, the width being varied from 2 to 6 m. depending on the capacity desired. (b) flat circular ring of 12m. external diameter rotating about the horizontal axis, supported on roller the drive being provided by hydraulic jack located at the top of ring. The ring is divided into 24 compartments called baskets by fitting perforated plates at right angles, of the circular girder. Hydraulic jack rotates this wheel by pushing against fixed bars fitted to the exterior of the wheel.

The ring completes one revolution in about 40 minutes, but this could be varied depending on the throughput desired. The power requirement is quite low about 1 hp. per 100 t. cane per day. The residence time of juice is 20 minutes while in the case of bagasse it is 30 minutes. For improving contact between juice and bagasse flowing in opposite direction pulsation is applied to the juice, which helps renew the juice layer in contact with bagasse.

4.5.2. Dewatering device—Sucaltan dewatering apparatus forms a special feature of 'Saturne' diffuser. This device consists of two rollers, the lower one of 1.5m dia. while the upper one has 0.75 m. dia. The larger lower roller is hollow and provided with holes over about 30% area, and teeth. The upper roller, with half the diameter of the other one has teeth but no perforations and is hydraulically loaded. The dripwet bagasse with about 85% moisture is passed through these two rollers and efficient drainage of juice on squeezing reduces the moisture to 70% i.e. reduction of 50% water.

4.5.3. Operation—The revolving annulus receives bagasse through a chute by gravity, the flow being facilitated by spray of scalding juice over the incoming bagasse. At the other end of diffusion cycle press water of low brix is applied near the bagasse discharge end, which flows by gravity in counter current manner to the flow of bagasse. There are during the
operation following zones.

(a) low brix press-water application at top.

(b) maceration zone involving immersion of bagasse, and gradual transfer of sugar from bagasse to juice

(c) the second scalding zone, where juice withdrawn from maceration zone is sprayed on bagasse after heating.

(d) first scalding zone in which the juice collected from the second scalding zone after it is enriched is limed heated and sprayed on to the incoming bagasse in the feeding chute in large volume, the ratio of scalding juice to bagasse being 5:1. Part of the juice treating the bagasse is sent to boiling house.

The exhausted bagasse flows into 'Sucaltan' dewatering apparatus through a feeding chute. The bagasse on partial dewatering has to be conveyed to one or two mills for further dewatering.

The press-water and scalding juice are limed and heated so as to maintain pH 6.5 and temperature of 75°C in the maceration zone. The presswater, limed to 8-9 pH and heated to 85°C is applied without settling. During operation of a cycle of diffusion, bagasse enters empty basket from the feed chute, by gravity, feeding being assisted by scalding juice. In the course of rotation of the wheel the basket enters heating zone where the bagasse meets spray of diffusion juice. Thereafter the basket enters the immersion zone and as it continues its passage upwards in the annulus hot press water juice is injected to further reduce its sugar content. The withdrawal of juices for recirculation at particular points at each stage viz. maceration, first scalding and final scalding is brought about by providing screens.

The incoming bagasse is weighed continuously on belt conveyor and the ratio of press water juice to be injected into the bagasse is automatically controlled. Likewise the temperature and pH of scalding juice as well as presswater are regulated.

4.5.4. Saturne diffuser is designed for bagasse diffusion and is preceded by one or two mills for primary juice extraction. Cane preparation with two sets of knives is adequate and suitable for the system. For dewatering the bagasse emerging from Sucaltan dewatering device one three roller mill should give normal results. Necessary conveyor units for transport of bagasse from mill to diffuser and for exhausted bagasse have to be installed.

4.6. Other designs—Besides above there are some more types of diffusers introduced in different sugar producing regions of the world. Few of them are described below—

4.6.1. Buckau Wolf—Burnett diffuser—This unit is a long rectangular tank. The bagasse is moved over a perforated slat conveyor which supports a 1.7 m. deep bed of bagasse. The juice percolating through the bagasse mat is collected in bottom tanks. The juice is pumped back and applied to bagasse in countercurrent to the flow of bagasse, getting progressively concentrated thereby towards the bagasse feed end. This is essentially a bagasse diffuser suitable for handling bagasse after primary extraction in a mill preceded by two knife sets or a knife set coupled with shredder.
4.6.2. F.S. Diffuser—This is an inclined bed diffuser in which instead of long rectangular conveyor, a series of inclined short conveyors are installed, extraction being effected by percolation of juice through the bagasse on the inclined surface and also by mixing of juice and bagasse at the lower end of each conveyor. The bagasse mat is thinner than in horizontal diffusers and percolation of juice is more effective. Moreover juice gets mixed with bagasse at the lower boots. Important feature of the diffuser is the easy manner in which the capacity of the unit can be enhanced by adding more inclined conveyors.

4.7. Industrial aspects—

4.7.1. In the last three decades the world cane sugar industry has witnessed major changes in the system designs in the process of manufacture and continuous cane or bagasse diffusion for juice extraction presents a significant departure from the conventional milling which has been practised for the past two-hundred years or so. The designs of diffusers presently in operation can be broadly classified into two categories viz., horizontal and vertical types.

In horizontal diffusers those of rectangular type are characterised by long bagasse conveying system supporting advancing bagasse bed. The De Smet and B.M.A. diffusers, installed in number of factories belong to this class. The D.D.S. diffuser is horizontal but inclined and not rectangular in shape as the other designs. The horizontal rectangular diffusers occupy more space than the vertical types. However the horizontal diffuser with circular bagasse bed as with Silver Ring design occupies much less floor space.

In the vertical bed Saturne wheel type design, the bagasse moves in the annular ring. This type occupies much less space as compared to other designs. Yet another design close to vertical bed type is the F.S. inclined bed diffuser, with a number of small inclined conveyers taking the place of one horizontal rectangular conveyor.

The vertical ring type or circular type of diffusers have severe limitations with regard to capacity enhancement.

The diffusers are equipped with automatic controls and instruments for regulating the various operating parameters like pH, temperatures, imbibition etc., which are very vital for proper operations, and obtaining good results. The instrumentation forms an important part of the total installation.

In world cane sugar Industry diffusers have been introduced in almost all major sugar producing regions like South Africa, Hawaii, Australia, Mauritius, South America and India, but have found wide acceptance in South Africa wherein over 40% cane is processed in diffuser installations. The cane diffusion is thus a well established process but does not pose a challenge to mill manufacturers as shown by the fact that new factories being set up in different countries are mostly equipped with milling tandems. In India about half dozen diffusers of D.D.S., De Smet and Saturne designs were installed in sixties and seventies but few of them were replaced by mills for two reasons.

(a) substantial expansion of plant capacity,
(b) failure to operate the diffusers in accordance with the specified parameters resulted
in poor performance. The standard specifications for sugar plants, formulated by Government of India recommend installations of mills.

5. OPERATING CONDITIONS AND THEIR INFLUENCE ON SUCROSE EXTRACTION

5.1 Diffusion is a process which needs to be rigidly controlled with respect to operating parameters. Each diffuser design calls for specific conditions to be maintained in regard to the operations and usually the factors that influence the extraction and throughput are (i) pH (ii) temperature (iii) retention time of juice and bagasse, (iv) rate of imbibition.

5.2 pH—With the exception of D.D.S. diffuser of Danish design, all the diffusers require lime addition to intermediate stages of juices being circulated and also the press water i.e. the thin juice from dewatering unit, for maintaining pH of 6.2 - 6.5 in the diffuser since at lower pH values inversion of sucrose as also corrosion of steel equipment are feared. Raising pH beyond this range will precipitate more calcium salts, with adverse repercussions on juice percolation through bagasse. Dosing of milk of lime has to be rigidly controlled with the help of pH controllers. Equally important is the thorough mixing of juice with lime, so as to avoid pockets of high alkalinity which give rise to destruction of reducing sugars, and formation of coloured compounds.

In D.D.S. diffuser the sugar extraction from bagasse takes place at the natural pH of juice in bagasse i.e. at 5.2 - 5.6 pH. Work of D.P. Kulkarni and J.R. Unde has shown minimum extraction of soluble salts, as indicated by conductivity measurements at 6 pH similarly reducing sugar % pol is also lower at this pH\(^1\) compared to that with milling. Sucrose inversion can take place at pH 5 or below.

5.3 Temperature—The temperature inside the diffuser has to be 70\(^\circ\)-75\(^\circ\)C for two major reasons; one for controlling the microbiological activity and secondly for better extraction. High temperatures besides improving rate of diffusion, reduce viscosity of juice and help better contact of juice with bagasse. Rein has observed increase in brix extraction of 0.22 by raising temperature by 5\(^\circ\)C from 75\(^\circ\)C, which is considered normal.\(^2\) Some diffusers in South African Industry, have been operated at 90\(^\circ\)C with possibly no ill effects.\(^3\) However, such high temperatures might retard the percolation rate through bagasse on account of the compacting caused by softening of the fibre. Nonetheless operating temperature in diffuser has to be minimum 70\(^\circ\)C for controlling microbial activity against the background of higher retention time in diffusers as compared to straight milling. Studies in South Africa on percolation type diffusers by L. McMaster and A.B. Ravno have shown substantial amount of lactic acid formation by bacterial fermentation which can be suppressed by maintaining temperature above 75\(^\circ\)C\(^4\) Alternatively it is suggested that this microbial activity can also be controlled by addition of formalin. In view of the longer retention of juices and bagasse in diffusion as compared to milling as also the large number of stages of juice circulation, it is imperative to play special attention to the maintenance of high temperatures in the interest of preserving sucrose in cane.

5.4 Retention time—Longer residence time of fibre and juice though conducive to increase in
brix extraction is however likely to give rise to higher colour formation and sucrose inversion. As against this shorter retention will lead to lower extraction efficiency. The duration of retention of fibre, which can be varied within limits, by changing speeds of conveyors and also the bagasse bed thickness, has been optimised to each type of diffuser. Generally the bagasse retention in the percolation type diffusion system is always of longer duration than that of the juice by 50-75%. Needless to state that cane diffusion will involve more residence time than bagasse diffusion.

Cane preparation—In the case of percolation type diffusers the cane preparation should provide even sized fine bagasse such that the juice penetration is not hampered and proper extraction can be effected. The trend in South African Sugar Industry for both cane and bagasse diffusers is towards fine preparation with preparation index of 90 or so preferably by installation of shredder along with knives. High preparation index opens up the cells and renders extraction by lixiviation easy. Proper preparation for diffuser would involve producing long fibres separated from each other which would be beneficial for extraction as well as percolation whereas short pieces of fibre increase bulk density and packing. In any case cane preparation resulting in fine and uneven size fibres is not conducive to penetration of juice applied to bagasse mat. On the other hand coarse bagasse feed will not permit proper contact of thin juice with juice associated with bagasse and will result in poor lixiviation or displacement. Moreover for the bagasse diffusers to yield good results the primary extraction has to be 65 and above, which is obtained with one mill when the cane preparation is reasonably good with preparation index of 65-70.

The Degree of preparation and the evenness of fibres of cane or bagasse determine to a large extent the pattern of juice percolation. When large part of juice sprayed on moving bagasse bed does not percolate downwards through the bed causing recycling, wherein considerable amount of juice goes back to the trough from which it was pumped a situation develops when flooding is observed resulting in fall in extraction. Main cause of flooding is too fine and uneven sized fibres of the bagasse mat through which the juice is passing or excessive quantity of juice unsuitable to conditions of bagasse. This affects extraction efficiency for three reasons:

one, the contact of bagasse with extracting fluid is insufficient. two, the displacement of juice in broken cells is poor, and thirdly the diffusion of juice contained in unbroken cells is poor. The ultimate effect is that the mass transfer process from juice in bagasse to dilute juice is hampered. High flow rate of dilute juice, should not exceed the limit imposed by flooding conditions. Similarly coarse preparation permits high flow rate without flooding but results in inadequate contact of extracting liquid with juice in bagasse. In short proper cane preparation calls for long and separate fibres, with high bulk density for maintaining optimum percolation of juice for achieving good extraction.

With Silver Ring diffuser, the cane preparation is of very high order with elaborate preparatory devices consisting of fibrizer and buster. The D.D.S. diffuser does not require fine preparation though primary extraction required is 65, and with one mill for primary extraction, the cane preparation with two sets of knives should suffice as the bagasse feed would be neither coarse nor fine.
5.5. Imbibition rate—Higher imbibition to the extent to about 200% fibre, which normally corresponds to a draft of 100% on cane gives good results, in any system of diffusion. However in South African sugar Industry very high figure of 344% has been reported by Lamusse with Extraction of over 96% pol in cane.

In diffusers certain minimum volume of juice has to be maintained, thus necessitating some minimum imbibition. However, the upper limit of draft would depend upon the percolation rate that is desired for maintaining the throughput. High imbibition leads to a good brix gradient between the juice contained in cane or bagasse feed and the presswater brix. Greater difference between these two serves as driving force for extraction. Imbibition water is added in most cases at the dewatering mills prior to last milling, the thin juice being sent to diffuser, or in some cases partially before the last mill and remaining in the last stage of diffusion. Use of hot condensates from evaporator, which are mostly alkaline, helps to some extent raise the temperature of thin juice. Whenever two mills are employed for dewatering, addition of hot imbibition will also help the extraction of juice from cells which have escaped unbroken from the diffusion process.

In India the imbibition percent fibre at Tanuku (A.P.) was 183% with draft of 94.96%, while operating De Smet diffuser which gave reduced mill extraction of 95.88. Studies on the operation of D.D.S. diffuser at Phaltan Sugar Works, have shown positive increase in reduced mill extraction with increase in imbibition though the advantage gained tapers off beyond 95-96% draft or imbibition % fibre of 178.7.

6. DEWATERING OF WET BAGASSE

One special feature of the diffusion system is the discharge of hot and dripwet bagasse with about 85% moisture and a temperature of 65°C. In order to bring down this high moisture to 48-50% level, special equipment like French press and Silver cone press were developed two decades back but later experience showed the use of mills to be more satisfactory and suitable for dewatering, in cane sugar mills. Two mills should suffice under normal condition, the feed to mills being effected through Donnelly chutes.

Light dewatering devices for reducing the moisture of diffuser bagasse by 10-15% have been developed by some manufacturers, which form part of the main diffusers. Drums of about 2m. diameter located on the bagasse mat of the discharge end of diffuser in B.M.A. and De smet designs which have the same length as the width of the bagasse mat, achieve little reduction in moisture but break the surface. By far the most effective dewatering device forming part of diffuser system is the 'sucaltan' dewatering arrangement consisting of two rollers through which the dripwet bagasse is passed and substantial reduction of moisture to the extent of 10-15% is achieved.

The real moisture reduction to normal level of around 50% is however accomplished usually in two mills or one five roller mill followed by one three roller mill. Following aspects need special consideration in respect of operation of mills for dewatering.

(a) feed to the first mill has to be arranged through a tall Donnelly type chute, in view of the very high moisture content of bagasse.
(b) Mills should be fitted with underfeed rolls.

c) The drainage at the first dewatering mill must be good. Deep and wide grooves are essential.

d) it should be possible to add imbibition water partially before last mill.

e) arcing of rollers should be practised.

(f) the mill settings have to be calculated taking into account the moisture conditions of bagasse.

The 'French screw press' or 'silver' cone press described earlier failed to gain popularity perhaps because of cost factor, even though their results are encouraging. In India with two dewatering mills the moisture content in final bagasse, was 50.5% at Andhra Sugar Tanuku where De Smet diffuser was operated while at Phaltan Sugar Works with three mills the final bagasse moisture was brought down to 48%.

7. THIN JUICE TREATMENT

Thin juice from dewatering mills referred to as presswater from an analogy of beet diffusion wherein the wet pulp is dewatered in press, is required to be treated for removal of suspended matter and impurities which would impede percolation rate in percolation type diffusers. This juice of 2°-4° brix, constitutes around 70-80% juice on cane which has to be recirculated in the diffuser. The treatment of this juice consisting of liming to pH 8 and heating to 100°C, followed by settling in clarifier with addition of flocculant forms essential part of many percolation type diffuser. The decanted hot clear juice is circulated while the settled mud is filtered along with mud from raw juice clarification in boiling house. Work in South Africa has shown the use of aluminium sulphate or phosphoric acid followed by liming to yield good results in clarification, when pH is either lower than 4.5 or above 9.5. Centrifuging the untreated presswater in solid bowl centrifuge results in good clarification but being costly, cannot be adopted.

In D.D.S. diffuser and 'Saturne' design no press-water clarification is advocated and the untreated thin juice from dewatering mills is returned to diffuser. In percolation type diffuser the necessity for thin press juice clarification arises due to the blinding of interstices of bagasse conveyed in diffuser and in one factory 'Empangeni' this problem has been solved by churning of bagasse bed, while using the untreated presswater, by means of vertical screws. Use of unclarified thin juice would certainly be a big step forward in the cane diffusion since it would eliminate one process operation of clarification and the extra equipment like settler, heater, pumps etc. associated with it.

8. INFLUENCE OF DIFFUSION ON EFFICIENCY AND RECOVERY

In milling squeezing the cane under heavy pressure alone does not give satisfactory extraction beyond 80-85% notwithstanding the high degree of cane preparation by means of heavy duty knives and different types of disintegrating equipment and it is essential to
use water for diluting the juice contained in bagasse. Thus was evolved the concept of compound imbibition involving recirculation of dilute juices on mills. Present milling practice involves diluting the juice in bagasse in 3 to 5 stages followed by squeezing for maximum recovery of juice in bagasse. In continuous diffusion, the juice in bagasse is repeatedly displaced by juice of lower brix at every stage, the number of stages being 10-15. Since thorough mixing of bagasse juice with the dilute juice or water is an essential prerequisite for recovery of maximum amount of sugar in cane the diffusion process certainly has an edge over milling in this respect as the diffusion process can ensure this mixing in view of the longer time of contact of bagasse with diluting juices, as compared to mills. Thus extraction is more positive in diffusion and the efficiency of extraction is always high. In India R.M.E. with milling diffusion plants employing De Smet diffuser and D.D.S diffuser system has been 95.8 and above and over 96% respectively with imbibition % fibre of 175 and 180-185% respectively. In Australian sugar industry over 97% R.M.E. has been reported with 200-300% imbibition on fibre. In South Africa where very high imbibition is practised in milling the corresponding figures are 97-98 R.M.E. with 250-400%. Under Indian conditions, in view of the pressing need for saving bagasse the imbibition % cane cannot go above 200 or so and the diffuser would be of advantage at these levels of imbibition compared to mills in view of thorough contact of bagasse with imbibition fluids. Thus it is beyond doubt that high extraction efficiency can be achieved provided the conditions with respect to cane preparation, primary extraction in the case of bagasse diffusion, draft, pH and temperature are adhered to.

9. LOSSES DUE TO STOPPAGE AND POOR SANITATION

9.1. In mill operation the bagasse and juice have a few minute’s residence and as such the sudden stoppage of the unit will not exert such adverse influence on the sucrose recovery from cane as with a diffuser which contains huge quantities of bagasse and juices in circulation, the retention time for these two being around 30 to 50 minutes and 20-30 minutes respectively. In milling diffusion any breakdown in any ancillary unit or any of stages of primary extraction or dewatering of bagasse results in stagnation of large quantity or bagasse and juice which result in

(a) destruction of sugar,

(b) increase in non-sugars extraction, both having deleterious effect on recoverable sugar from cane being processed.

During planned stoppages for cleaning and maintenance when the levels of bagasse and juice could be brought down the losses can be substantial. Observations on the effect of cleaning day stoppages of 24-26 hours, on the composition of juice in the D.D.S. diffuser at Phaltan Sugar Works have shown increase in R.S. % pol ratio by 200-250% during the period of shut down. In this case low pH and high temperature contributed to decomposition of sucrose. During short and sudden stoppages loss of sucrose is inevitable. In effect the diffusion system calls for smooth and uninterrupted operation.

9.2. Sanitary conditions in diffuser system can be maintained properly by maintaining high temperature and avoiding stagnation of mass at any point. Sanitation in the system can
be made more positive by use of effective biocides and it is essential to provide arrangements for addition of biocides in every cell and juice receiving tanks. The sucrose loss due to microbiological activity does not figure in the usual sugar accounting and it is all the more necessary to pay due attention to this aspect.

10. EXTRACTIVES AND NON-SUGAR INCREASE

As the brix extraction in diffuser is more positive and high compared to conventional milling for the same levels of imbibition, question arises as to whether non-sugars are also extracted to higher extent since ultimately the cane processing units are primarily interested in higher recoverable sugar. Studies conducted in Australia with percolation type diffusers have shown that diffuser juices contain higher amount of non-sugars, and colouring matter as also colour precursors but lower quantum of high molecular weight compounds than juices from accompanying milling units.\textsuperscript{12} Studies on the operation of D.D.S. diffuser in India have revealed higher ash and CaO extraction but lower gum content in diffusion as compared to milling when draft maintained was around 95%.\textsuperscript{13} Experience with this diffuser at Phaltan Sugar Works in India showed—

(i) higher molasses production on account of higher non-sugar extraction,

(ii) higher extraction and

(iii) overall higher recoverable sugar with this system.

General findings in South Africa Sugar Industry are—

(i) molasses production in factories operating diffusion is higher by 10% than those equipped with mills,

(ii) there is no difference between molasses purities of factories employing either milling or diffusion,

(iii) reduced boiling house recovery is higher in most of the diffusion operating plants than those with mills.\textsuperscript{14}

In India as per experience with two types of diffusers viz. the D.D.S. diffuser and De Smet diffuser where optimum conditions of operation were adhered to, favourable results have been reported in respect of recoverable sugar with bagasse diffusion system despite higher production of molasses as compared to milling, when the draft was maintained around 95%, and imbibition % fibre of about 180%.

In sugar factories employing very high levels of imbibition - of the order of 300-350% fibre-wherein thorough contact of imbibition fluids with bagasse is ensured by special devices, the recoverable sugar as also extraction is certainly high. It is doubtful whether replacement of such mill by diffusion system will give any benefits with regard to recoverable sugar from cane, with the same level of imbibition. However with lower levels of imbibition 170-200% fibre the diffusion system should be definitely advantageous in sugar recovery aspect provided the conditions of operation are followed in toto. Failure to observe the norms with respect to cane preparation, retention time, pH,
temperature and continuity of operation leads to losses and poor results of the diffusers, and in the absence of proper operating conditions diffusers would give poor performance.

11. COMPARISON OF MILLING AND DIFFUSION

11.1. Steam Consumption—In diffusion the entire mass of bagasse and juice is maintained at 70°C-75°C for which heating either the juice being circulated or the entire diffuser contents as in immersion type diffusers is essential. The heated juice coming out of the diffuser raises the raw juice temperature and to a certain extent reduces the load on juice heating in clarification but the heat energy associated with bagasse is not recovered from the process point of view. The total extra steam requirement is around 3% on cane taking into account the heat energy recovered in juice while actual steam consumed would be about 4-5% cane. The vapour from vapour cell or first body of evaporator can be utilised for heating operation in the diffuser system. Nevertheless this steam consumption represents extra steam requirement in diffusion over that for milling.

11.2. Power—The power requirement of diffuser station can be classified into three sections

(i) power for diffuser,

(ii) power for running the conveyors and

(iii) drive for pumps.

In the percolation type diffusers the last one viz. drive for pumps operated for circulation of juices accounts for major power consumption. A milling tandem to give high extraction has to be equipped with efficient cane disintegration units like Shredder so as to obtain 80-90 preparation index. In South African sugar industry the various diffusers installations incorporating preparatory devices like shredders the installed power is about 20% less than that for equivalent milling tandems. In case the diffuser operation requires coarse preparation, with knives, the saving in power could be more i.e. upto 30% since the diffuser would be a substitute for two or three mills of a milling tandem. The high pressures and running of heavy rollers of mills call for provision of higher power than the diffusers involving simple equipment and no pressures.

11.3. Cost—Capital cost of a diffuser is expected to be somewhat lower than three-mills of a six mill tandem since performance wise the milling diffusion plant can be compared with a six mill tandem fitted with elaborate cane preparation equipment. However the fact that mills are being manufactured on a much bigger scale than the diffusers which have not appreciably affected the market for mills, renders the comparison of costs of two systems unreliable.

11.3.2 As regards the maintenance costs of diffusers these are found to be much less as compared to two or three mills, which it is supposed to replace in the case of bagasse diffusion, in view of the absence of high pressures or speeds of different units of a diffusion system as shown by the experience in Indian factories and sugar mills in South Africa. In diffusion the pumps are the main units which constitute a major source of
maintenance requirements and some designs of diffusers envisage installation of a number of pumps. In region where cane harvesting is mechanised the sand accompanying the cane causes heavy wear of internal parts of pumps and this problem is sought to be solved by use of erosion resisting material of construction for impellers as also by reducing speeds of pumps.

12. PROBLEMS OF CAPACITY VARIATIONS

As stated earlier the conditions of operation are rigid in diffusion system with regard to cane preparation, pH, temperature and retention, which call for strict vigilance, while in milling it is only the uniformity of feed and imbibition which need to be taken care of, once the mills are properly set. It needs to be emphasised that the performance of diffusion system can be poor and worse than with milling alone unless the operating parameters are maintained at the specified levels.

Mills possess greater flexibility with respect to expansion of capacities as shown by the fact that by addition of mills (upto six) or by installing new mill feeding units like T.R.P.F. or pressure feeders in the existing tandem the capacities of mills can be substantially augmented. A case in point is the expansion of mill capacities achieved in Deccan Sugar Industry from 1250 to 3,000 tc.d. by additions of new preparatory devices, mills, pressure feeders etc. This flexibility is practically absent in the case of diffusers, wherein with the exception of F.S. design which admits of augmenting capacity by increasing the number of inclined beds, the capacity increase cannot be accomplished easily without elaborate modifications.

In a crushing campaign the mills have to handle ± 15-20% cane to suit the variation in cane supply, as compared to the rate for which they are set for good performance. The desired performance is affected accordingly due to over crushing or under crushing. Similar case holds for diffusion system as far as the overall results are concerned.

13. FUTURE OF DIFFUSERS

Milling depends on 3-5 times contact of thin juice or water, followed by squeezing out juice from wet bagasse under high pressures, for proper extraction, whereas in diffuser the replacement of high brix juice by lower brix juice is resorted to in a number of stages 8 to 13 or more. Milling of sugarcane has been in vogue since the birth of sugar manufacturing industry while the continuous diffusion of sugarcane is of recent origin, and has not yet replaced milling even in new installations in a big way. In many factories diffusers were installed to work along with existing mills for capacity expansion. Installation of diffuser for plant expansion, making full use of existing mills to serve for

(a) primary extraction and

(b) dewatering of bagasse, in old plants appears to be economical proposition.

From the energy requirement angle and from the point of view of reducing maintenance costs, the diffusion has an edge over milling. Nevertheless the future of diffusers is
uncertain in view of the fact that in the recent past in new factory installations in India and many other countries milling has found acceptance. Further improvements in new designs of diffusers should be based on following considerations:

(i) number of stages of washing to be reduced.
(ii) thin juice from dewatering equipment to be recirculated without clarification in percolation type diffusers.
(iii) pH inside the diffuser to be around 6.0 by suitable addition of lime.
(iv) facility for capacity expansion of installed units.
(v) application of light squeezing preceded by spray of thin juice.

With incorporation of above modifications, a bagasse diffuser in combination with a few mills should prove to be superior to the existing milling in respect of performance, maintenance costs and energy consumption.
REFERENCES

7. Ibid.
15. J.P. Lamusse 'Sugar Technology Reviews' Vol 7 December 1980 p. 244-245.
Fig. 1. KNIVES

Fig. 2. FIBRIZER
GRUENDLER SHREDDER

Fig. 3.

STANDARD HOUSING

SQUIER HOUSING

Fig. 4.
Fig. 5. MILL HOUSING-INCLINED
Fig. 6. CIRCUMFERENTIAL GROOVING

Fig. 7. MESSCHAERT GROOVING

Fig. 8. SLAT TYPE INTERMEDIATE CARRIER
T. R.P. F

Fig. 9.
STANDARD COMPOUND IMBIBITION

Fig. 10.

MACERATION BATH

Fig. 11.
Fig. 12. DE SMET DIFFUSER

Fig. 13. B.M.A. DIFFUSER
Fig. 14.

SILVER RING DIFFUSER
SATURN DIFFUSER

Fig. 15.
D.D.S. DIFFUSER

Fig. 16.

D.S.M. SCREEN

Fig. 17.
4. CLARIFICATION

PART 1

REAGENTS USED IN JUICE CLARIFICATION

1. The raw juice is turbid and contains undesirable impurities which have to be eliminated so that the concentrated clear juice or syrup is suitable for sucrose crystallisation in boiling strikes from which white sugar is produced. Thus, the treatment in purification should impart transparency as also brilliant appearance to juice and syrup. Various chemicals and number of organic and inorganic substances have been proposed so far for bringing about the desirable results in clarification. However the choice of chemicals in technological operation is determined by considerations in regard to-

(i) costs,
(ii) actual results obtained in large scale adoption
(iii) effects on recovery of sugar,
(iv) impact on quality of sugar,
(v) influence on further process operation.

Needless to state that the agents to be used in sugar manufacture should not persist to the final product viz. sugar and in case find their way to sugar the residual concentration should be below the toxic limits, laid down by Food and drugs standards. There are two types of reagents used. One, those that are used in substantial amounts like lime, phosphates, sulphur etc. as main clarificants and two, those additives employed for assisting certain operations, like settling aids.

2. LIME

2.1. Lime is the oldest and cheapest chemical being used in sugar manufacture, as a juice clarificant. The quantities consumed depend on the process adopted for clarification such as—

(i) for defecation consumption is 0.1 to 0.15% cane.
(ii) for sulphitation 0.15 to 0.2% cane.
(in) for carbonation 15 to 2% cane.
In Indian factories lime i.e. calcium oxide CaO is used in the form of lumps or powder but in Louisiana hydrated lime i.e. Ca(OH)$_2$ in powder form or pulverised quick lime has replaced the lumps completely. Lime is obtained from high grade limestone by burning it in kilns. Many Indian sulphitation plants prefer producing lime in kilns, installed at the factory site procuring limestone and coal, for their process use.

2.2. Limestone burning

2.2.1. Lime stone i.e. calcium carbonate when heated is decomposed with the formation of calcium oxide and carbon dioxide.

\[
\begin{array}{llll}
\text{CaCO}_3 & \text{CaO + CO}_2 \\
100 & 56 + 44 \\
\end{array}
\]

Thus pure calcium carbonate on dissociation will yield 56%, CaO. The reaction is endothermic heat absorbed being 42.5 K Cal. per mole. The optimum temperature range is 1100°C to 1300°C, though the dissociation commences at 600°C. Burning at temperatures exceeding 1350°C for longer periods results in production of dead burnt lime. Higher SiO$_2$ or MgO content in limestone can cause formation of 'dead-burnt' lime even at 1200°C. Properly burnt lime is highly porous, light in weight and slakes quickly to form Calcium hydroxide i.e. Ca(OH)$_2$ on account of the easy penetration of water molecules in the atomic interspaces. On the other hand the dead burnt or inert lime is the result of atomic rearrangement and can have 25% higher density compared to a properly calcined lime, which adversely affects slaking process.

2.2.2. Lime Kiln-In sulphitation factories the lime kilns installed are of open type and the CO$_2$ is blown into atmosphere. The feed consisting of about 10 cm. pieces of limestone mixed with about 30% coal is given from top and the lime drawn off from bottom opening. In carbonation plants the lime kilns are fed limestone pieces of about 10 cms. along with about 10% coke and CO$_2$ generated is purified, compressed and led to carbonation tanks. The amount of heat required for conversion of limestone to lime in an industrial Kiln is about 700 kilo cal. per kg. of limestone. The limestone used for burning should be even sized as large pieces after calcination will be found to be partially burnt while small pieces will be overburnt. Both these conditions are to be avoided. In carbonation factory a continuous limekiln with closed top is necessarily installed outside the factory building in as much as both the products of limestone burning viz. CaO and CO$_2$ are required for clarification and the lime requirement is pretty high compared to other process.

2.3.1. Source of calcium carbonate

*Quality of lime*—Source of calcium carbonate is mostly the lime stone quarries or the coral deposits. CaCO$_3$ content of commercial limestone varies from 85-95%, the other impurities being silica, iron alumina, magnesia, sulphates and alkalies. From the point of view of sugar manufacture the following norms have been specified by Java Experiment station.

1. SiO$_2$ 1%, Max.
2. Fe$_2$O$_3$, Al$_2$O$_3$ Max 1%
3. MgO 1% Max.
4. SO₄ 0.1% max

Corresponding impurities in lime will be within following limits.

(i) Moisture, (ii) HCL insoluble matter, (iii) SiO₂ (iv) Fe₂O₃Al₂O₃ and (v) MgO

Maximum 2%

SO₄ Maximum 0.2%

Carbonates as CO₂ 2.0%

Lime i.e. CaO is highly hygroscopic and forms calcium hydroxide on reacting with water.

CaO + H₂O → Ca(OH)₂ + 15.2KCal

The reaction is exothermic and heat is evolved during reaction.

CaO or lime absorbs moisture and CO₂ from atmosphere and thus should not be exposed. Under moist conditions lumps of lime exposed to atmosphere crumble to small pieces and are disintegrated. Prolonged exposure of lime to atmosphere results in formation of calcium carbonate due to reaction with CO₂.

Solubility of Ca(OH)₂ in water is very low as one part of Ca(OH)₂ dissolves in 790 parts of water, but the solubility of CaO in sugar solution increases with concentration of sucrose but decreases as temperature rises. The milk of lime prepared in the factory consists of fine suspension of Ca(OH)₂ in water besides the hydroxide in solution. The CaO content of different concentrations of milk of lime expressed in terms of Beaume is as given in Table 2.

2.3.2. Test of Lime—It is essential to carry out routine tests of milk of lime in the factory as under:

(a) Available CaO. 2.5 gms. of lime are pulverised, weighed and transferred to 250 ml. graduated flask, using 5% aqueous phenol as rinsing liquid. After frequent shaking of the contents of the flask for one hour the flask is made up to mark with phenol solution. The contents are well mixed and filtered. 100 ml. of the filtrate is titrated against N/1 HCl using methyl orange as indicator. % CaO = ml. HCl x 0.028

In place of 5% phenol 30°-40° Bx pure sugar solution can be used but the time of contact with intermittent shaking of the lime and sucrose solution will be 3 hrs.

(b) Solubility test—To 500 gms. of lime to be tested, is added pure water in a glass flask. Subsequently on disintegration of the lime it is made into a paste. After waiting for ten minutes (from the time water addition is started), more water is added to prepare thin milk of lime. This dilute solution is strained through fine mesh with 0.1 mm. opening. In a second test, the lime paste is diluted after waiting for an hour and residue determined as in the previous test. The residue is rubbed over screen and washed with water till washings are clear. It is then dried and weighed. The results are expressed on percentage of lime.

The chemical analyses of lime or limestone can tell the total CaO along with the presence
of various impurities but for chemical reactions in the process it is important to find out available CaO content which needs to be determined as a matter of routine.

As regards the slakability test, it signifies the control on the burning of limestone and the extent of overburned lime i.e. dead burnt lime which takes a long time to slake and can cause increase in pH particularly in the clarifier after some time. According to Douwes Dekkar good grade lime should contain 85-90% available CaO while the classification of lime on the basis of slakability tests would be as under:

(i) Residue after 10 minutes < 4% and after 1 hr < 2% Good
(ii) Residue after 10 minutes < 4% and after 1 Hr. > 2% satisfactory
(iii) -do- -do- 4-10% —do— < 2% satisfactory
(iv) -do- -do- 4-10% -do- 2-7% Doubtful quality
(v) -do- exceeding 4-10% - do- exceeding 7% unsatisfactory

2.3.3. Tests of milk of lime—The milk of lime is tested for available CaO and dispersion of solid particles in the lime cream. Available CaO is estimated by the Phenol method as in the case of solid lime while an additional simple test with regard to settling of particles is conducted as follows:

Settling test—100 ml of milk of lime is taken in a measuring graduated cylinder and allowed to remain for two hours, after which the volume of settled portion separated from clear liquid is noted. The norms of quality are as under:

90-95 ml. marks the quality is excellent.
Between 60-90 ml. Quality is satisfactory.
below 60 poor quality.

It needs to be stressed that lime being the principal reagent for clarification daily control on quality of lime and milk of lime is of utmost importance. Analytical control on quality of lime on the above lines will be very helpful in the conduct of process operation.

3. SULPHUR

3.1. Sulphur is an important chemical used in plantation white sugar manufacture for generating SO$_2$ in the clarification house. Elemental sulphur occurs mostly in U.S.A., Italy and Japan, though in sulphide form it is found in copper, iron and other mineral deposits. The atomic weight of sulphur is 32.06 while its melting point is 113°-115°C At 444.7°C which is the boiling point of sulphur at ordinary pressure sublimation occurs. For use in sugar manufacture sulphur must be of very high purity (above 99%), the maximum permissible levels of impurities being—

(i) Moisture-1%,
(ii) ash 0.1%,
(iii) bituminous matter -0.1%,
(iv) arsenic 0-05%.
3.2. Sulphur content—10gms. of sample is extracted with carbon disulphide and after separating the extract, the residue is heated for 1/2 hr. at 100°C to convert the unextracted amorphous sulphur into soluble form. This is followed by another extraction with CS$_2$. Sulphur content is arrived at by deducting moisture and residue from the weight of sample. Moisture is determined by heating powdered sulphur at 70°C for 2 hrs. Another simple test of combustion property of sulphur is to heat it in a crucible till inflammation commences. Good quality sulphur should require no further supply of heat and no film due to presence of ash or organic components, be formed. Such film formation retards combustion in stationary closed burners. Residue after combustion should not exceed 1% of the sulphur under test, though for rotary burners higher figure may be acceptable.

4. PHOSPHATES

Phosphate addition to raw juice is being practised since long in both raw sugar and plantation white sugar manufacture. In fact along with lime, phosphates are commonly employed in production of all types of sugar viz., raw, plantation white and refined sugar. The source of phosphate compounds added in clarification is the naturally occurring phosphatic rocks. Formerly single super phosphate and triple superphosphate were added in the form of slurry or extracts. Single superphosphate is manufactured from rock phosphate by the action of sulphuric acid.

\[
[\text{Ca}_3(\text{PO}_4)_2]_3 \text{CaF}_2 + 7\text{H}_2\text{SO}_4 \rightarrow 3\text{Ca H}_4(\text{PO}_4)_2 7\text{CaSO}_4 + 2\text{HF}.
\]

The single superphosphate contains 16-17% P$_2$O$_5$.

Triple superphosphate is prepared by reacting orthophosphoric acid with rock phosphate.

\[
[\text{Ca}_3(\text{PO}_4)_2]_3 \text{CaF}_2 + 14\text{H}_3\text{PO}_4 \rightarrow 10\text{Ca}^+ (\text{PO}_4)_2 + 2\text{HF}
\]

T.S.P. contains about 45-46% P$_2$O$_5$.

Other forms of phosphate suggested are dicalcium phosphate and ammonium phosphate out of which the former is soluble in ammonium citrate and to some extent sulphurous acid, while the latter is soluble in water. In recent years phosphoric acid containing about 55% P$_2$O$_5$ is being used in preference to any one of superphosphates due to—

(i) ease of handling

(ii) absence of impurities and

(iii) high P$_2$O$_5$ content.

Studies on using different forms of phosphates by D.P. Kulkarni in white sugar manufacture by sulphitation process have led to following conclusions:

(i) For the same P$_2$O$_5$ free acid is higher in S.S.P. than in other types of phosphates.

(ii) Sulphates are very high in ammonium phosphate and low in T.S.P.

(in) At high dilutions CaO content in S.S.P. extract is much higher than in T.S.P. extract.
(iv) Ammonium phosphate releases ammonia in the evaporator condensates and brings about corrosion of brass tubes. Thus it would be desirable to use phosphoric acid or triple superphosphate extract for clarification. Moreover the addition of phosphoric acid or phosphate should be in proportion to the quantity of juice flow for which special devices should be installed by which fixed predetermined dose of phosphate will be given at the time of each raw-juice weighing scale tipping.

5. MAGNESIA

Magnesium oxide MgO has been proposed as clarificant in partial replacement of CaO because of its beneficial effects on reduction of scale formation on heating surface of evaporator. MgO with an atomic weight of 40.03 as against 56 of CaO can replace 1.39 times the weight of the latter. According to Hugot good results are obtained in defecation, when about 50-80% lime dose is replaced by MgO and it is convenient to start with a mixture containing higher proportion of MgO and later gradually increase the lime proportion. The evaporator tubes remain clean and where scale formation on heating surface poses a serious problem magnesia offers solution for such conditions. MgO is much costlier than lime and its ultimate adoption is to be decided on the basis of economic benefits. In sulphitation factorises in India Magnesia has been given trials in some factories, however the Indian Industry has not adopted its use. The large scale trials conducted by D.P. Kulkarni at Phaltan Sugar works showed that the clarified juice had turbid appearance which would exert adverse influence on white sugar. More recent development of antiscalant chemicals which are found effective in reducing formation of scales in evaporator have rendered the use of Magnesia as unnecessary.

6. BENTONITE

Bentonite is a clay consisting of magnesium aluminium silicate MgO, Al\(_{2}\)O\(_3\)/5SiO\(_2\) nH\(_2\)O, with 5-8 water molecules, which swells in water. The size of the particles of bentonite being very small < 20µ surface provided by particles of clay is pretty large - exceeding 100 m\(^2\)/per gm. which accounts for its absorptive power. Furthermore the bentonite is characterised by its base exchange property and the cations of this clay are exchanged for the cations of the solution treated. Experimental work with molasses in Java has shown removal of SiO\(_2\) and CaO by two different clays viz. Montana clay and acid clay. In Argentina colloidal bentonite was added to juice in sulphitation factory producing direct consumption white sugar and good results have been reported with reduction in consumption of sulphur as also lime and better elimination of organic matter which had salubrious effect on boiling because of lower viscosity. More than 150,000 t. sugar was produced in Argentina in three seasons by this process. Another form of Bentonite KWK Volclay is reported to have given good results with refractory juices in Puerto Rico.
B. MISCELLANEOUS AGENTS USED IN SMALL QUANTITIES

7. SURFACE ACTIVE AGENTS

Surface active agents of cationic type are expected to remove colloids from raw juice substantially when added to the normal purification process. Use of Cetyl pyridinium bromide to juice in the defecation of juice gave promising results in the laboratory experiments conducted by N.A. Ramaiah as regards removal of colouring matter and colloids. Perhaps cheaper surface active additives may bring about further improvement in sulphitation process, in regard to removal of colloids.

8. FLOCCULANTS

A number of synthetic flocculating agents have come into use in the last two decades. These flocculants are synthetic high molecular weight polyacrylamides which are partially hydrolysed. Their efficacy as settling aids depends on the molecular weight which ranges between 7 to 10 million and the degree of hydrolysis. These compounds can be either anionic, cationic or nonionic, and serve as bridges among particles of precipitate and thus bring about formation of bigger aggregates of flocs. They are added as 0.05 to 0.1% solution in water at the rate of 2 to 5 parts per million parts of juice, to the treated juice in the pipe connecting flash tank to clarifier. A number of these polyacrylamides have come into market and their use has become absolutely essential when dealing with refractory juices or during periods of difficult settling as experienced in Deccan. Moreover their regular use in the process with installation of trayless clarifier has reduced the time of juice retention to 15 to 60 minutes. For improving settling rate and increasing the clarifier through put the addition of synthetic flocculant is essential. Thus the introduction of synthetic polyacrylamide as settling aids has been a significant advance in the process of clarification.

In Indian industry Separan A.P. 30 and Sedipur were introduced in sixties and were found very effective in rapid settling of sulphitation treated juice in Deccan during periods of high mud trouble which coincided with high recovery month of the season. Since then a number of new synthetic flocculants have been introduced, under different trade names. Large scale trials in a sugar mill in Deccan by D.P. Kulkarni in early sixties showed that the polymer Separan AP30 when added to suphited juice at the rate of 5 ppm. increased the rate of settling 2 to 4 times reducing the final mud volume by 20-40%. Thus, besides rapid rate of settling the final mud volume reduction is achieved by these flocculants. The choice of suitable polymer for use on large scale should be decided by actual settling tests in the laboratory.

9. ENZYMES

Enzymes are biological catalysts, consisting of protein molecule and are industrially produced from microorganisms. They are specific in their action and leave no undersirable residue in the final product. In sugar manufacture in the strictest sense they
are not employed in juice purification process; nonetheless their addition in the stages preceding or succeeding clarification to overcome the problems in processing created by the presence starch and dextran, is essential.

(A) Amylase—Starch is a polysaccharide composed of amylose and amylopectin in the ratio of 1: 4, out of which the amylose exerts depressing effect on the filterability of raw sugars. The starch granules are solubilised at 70°C and very little of it is eliminated in purification process either by defecation or sulphitation. Because of its mellassigenic effect and the contribution to increase in viscosity in pan boiling starch content above certain level 400-500 ppm. is considered undesirable. Moreover much of the starch finds its way to sucrose crystals and starch content in sugar beyond 150 ppm. creates problems in filtration in the refining of raw-sugar. Enzyme Amylase hydrolyses starch at temperature 60°-70° and pH 6.5, into oligosaccharides and other polysaccharides according to studies conducted in South African factories.12 An amylase Termamyl of Novo A/c enzyme is recommended to be added at the entry point of the second body of the evaporator, since it is suitable and effective at 90°-95°C. The enzyme is diluted ten times before use. If a particular type of amylase is effective at 70°-80°C in its action on starch it is added at the entry to the last but one vessel of evaporator. Perk recommended withdrawal of syrup from 3rd body of quadruple into a tank with thermostatic control and retention of the same in contact with enzyme for 20 minutes for efficient starch hydrolysis before the syrup is taken into last vessel of the evaporator.13

(b) Dextranase—Dextran is produced by bacteria Leuconostoc Mesenteroides in canes which are crushed after prolonged postharvest delay and in even in mills. Dextran is a long chain polymer of glucose molecules joined together by alpha 1:6 linkage and possesses very high molecular weight (5 x 10^6). It increases viscosity in boiling and contributes to higher loss of recoverble sugar. At the crystallisation station dextran inhibits the growth along B axis of the sucrose crystals which elongate along the ‘C axis. According to the findings of Tilbury elongation of sucrose crystals of 2.3 is noticed in ‘C massecuite boiling with dextran level of 1.3% solid, as against normal 1-1.2.14 Use of specific enzyme dextranase results in partial reduction of dextran concentration and the residual dextran is of lower molecular weight which does not affect the crystallisation by increasing viscosity or suppressing the growth of crystals along B axis. The dextranase enzyme is effective at pH 4.5-5.5 and temperatures 50-60°C, conditions which make its addition essential at raw juice stage before heating. The optimum reaction time is 15-20 minutes, while the dosage is 10-20 ppm. of juice for hydrolysis of dextran.

The dextranase is commercially produced from certain strain of Penicillium, and its use or choice should be governed by consideration of cost. This enzyme can solve the problems emanating from introduction of dextran generated from staling of cut cane at the expense of sugar in the process and it is essential that greater emphasis is laid on preventing this dextran formation by control of post-harvest delay in processing and good mill sanitation.
10. DIATOMACEOUS EARTH

Diatomaceous earth or Kieselguhr is essentially an inert filter aid with practically no power of absorbing impurities in sugar bearing materials. It was used in Java for improving filtration of settled muds after defecation or sulphitation. The important characteristics of good quality Kieselguhr are

(i) improving filterability of sugar bearing liquors or juices,

(ii) it should not contribute soluble matter when mixed with water.

In short it should be real inert filter aid. On account of the costs involved now a days, raw or plantation white sugar plants do not use this material but in refineries it is employed in all Alteration operations - particularly the decolourisation stage.
REFERENCES

2. Ibid p. 379.
7. D.P. Kulkarni, unpublished work.
PART II
CANE JUICE CLARIFICATION

1. OBJECTS OF CLARIFICATION

Juice received from the mills or diffuses commonly termed as raw-juice or mixed juice is turbid in appearance and contains besides suspended impurities of cane origin like fine bagacillo, a number of impurities either in dissolved state or in colloidal condition. The impurities in dispersed and suspended state include soil and fine particles of bagasse extracted during milling, and constitute around 0.3 to 0.5% of the juice. Approximate composition of mixed juice in Indian sugar factories is presented in Table 1.

Cane juice clarification aims at

(a) elimination of suspended impurities and colloids.
(b) removal of maximum amount of nonsugar components in solution
(c) imparting clarity and transparency to juice.

There are different systems of clarification but the main object is to eliminate maximum quantum of nonsugar impurities from the juice. The choice of a particular system of clarification is determined by the type of sugar to be produced. The defecation of juice is employed for manufacture of raw sugar while plantation white sugar plants follow either sulphitation or carbonation process of cane juice purification. In every process of clarification, the treatment of juice by heat and clarifying agents results in formation of precipitate which when separated, yields transparent juice. Yet another common feature of all the purification processes is the use of lime and heat as agents in combination with different other reagents. Irrespective of the method of clarification, it must be noted that the results of clarification have a great bearing on the subsequent sugar crystallisation process as well as the overall efficiency of the process of sugar manufacture.

2. ESSENTIAL PREREQUISITES

The main objectives of any clarification process are

(i) to remove as much amount of non-sucrose component as possible so as to render the subsequent crystallisation free from complications for producing white sugar and bringing down loss in final molasses.
(ii) to reduce the colour precursors and colourants
(iii) to produce brilliant light coloured clear juice free from suspended impurities.

Since the deficiencies or inadequacies in the operation of clarification have adverse impact on the quality of white sugar as well as the losses in process in plantation white sugar manufacture the process of clarification plays a crucial role in view of the fact that the marketable sugar is crystallised out from concentrated clarified juice termed as syrup.
Keeping in view the role of clarification in the entire manufacturing process and the fact that the results of clarification have to fulfill the aims of entire manufacture of good quality sugar at minimum cost the desired characteristics of juice clarification can be stated in brief as under—

(i) Rise in sucrose purity from raw juice to clear juice indicative of the degree of non-sucrose removal which brings down the formation of molasses as the nonsucrose constituents are responsible for molasses formation.

(ii) Sucrose which is unstable at low pH coupled with heat, has to remain intact and undecomposed,

(iii) Reducing sugars with their vital role in bringing down sucrose retention in final molasses, should as far as possible not be destroyed. High pH and temperature cause the decomposition of reducing sugars, which is quite high 25-30% in carbonation and very low in sulphitation 0.1 to 0.5%.

(iv) Increase in inorganic salts like silica, iron, sulphates results in undesirable scale formation in evaporator which has to be avoided by exercising rigid control on quality of chemicals employed.

(v) The process must be amenable to continuous operation and automation.

(vi) In the context of the entire factory operation, the process has to be energy efficient.

3. DEFECATION

3.1. Defecation of juice employing mainly lime and heat as agents, is probably the oldest and cheapest method of juice purification. It is more or less established that for optimum results the juice must contain 300 mgms. of P₂O₅ per litre and in case the juices are deficient in natural phosphate inorganic phosphates or phosphoric acid are added to bring the P₂O₅ content to the required level. The lime added besides neutralising the free organic acids, forms insoluble tricalcium phosphate Ca₃(P₂O₅)₂ precipitate which occludes colloids and suspended impurities. There are different variants of lime defecation methods in vogue in different regions.

3.2. Cold liming—In this method followed prior to 1920, the cold juice is limed to pH 7.8 - 8.3 and heated to 103°-105°C. After releasing the pressure, the vapours are vented out and the juice at about 100°C is sent to subsider for settling. It is reported that pumping of cold alkaline juice led to development of 'Leuconostoc' resulting in blocking of pipe lines due to the accumulation of dextran and gummy matter.

3.3. Hot Liming—According to this method the cold juice is heated to 70°C before treatment with lime to raise pH to 7.8; the treated juice being reheated to 103°C before being sent to subsider.

In Indian Industry the procedure followed where raw-sugar is to be produced involves following steps—
(a) to the weighed juice phosphate in the form of triple superphosphate solution or phosphoric acid is added to bring the $P_2O_5$ level of juice to 300 ppm.

(b) The juice is heated to 70°-75°C in juice-heater.

(c) The heated juice is treated with lime in continuous treatment tank, to pH 7.4 - 7.6.

(d) The limed juice is heated to 100°-102°C and sent to continuous clarifier.

(e) The clear juice from the clarifier or subsider is continuously drawn by overflow and sent to evaporator.

(f) The underflow or mud is sent for filtration to vacuum filter.

(g) The turbid filtrates from filter are sent to weighed juice receiving tank.

Heating prior to liming has the advantage of coagulating the colloids like albumin or siliceous compounds at low pH of juice and in Java the practice was to heat raw-juice to boiling point prior to liming followed by heating again to 103°-105°C.

According to Marches development of hot liming has helped to maintain constant pH difference between the limed juice and the clear juice from the clarifier. He further states that with modern juice heaters, the time of contact of juice with heat (100°C) being 5-7 minutes the inversion is negligible and the further adds that there is no objection to preheating juice to 90°C before lime addition.\(^1\)

3.3. Fractional liming and double heating—This method developed in West Indies has been found to be effective in clarification of refractory juices. The procedure adopted is to—

(i) add lime to cold raw-juice to pH 6.2-6.4.

(ii) heat the limed juice to boiling.

(iii) add remaining dose of lime to pH of 7.6.

(iv) heat again to boiling temperature before sending it to clarifier.

This procedure had resulted in better settling and clarity of juice together with higher rise in purity.\(^2\)

In view of the increasing use of modern settling aids and proper control systems in regard to pH and temperature the sequencing of lime and heat treatment adopted in India during periods of raw-sugar manufacture appears to be most suitable.

4. SOME CLARIFICATION SYSTEMS ADOPTED IN THE PAST, WHICH HAVE NOW BEEN ABANDONED ARE AS UNDER:

4.1. Saccharate method—Calcium saccharate is used as alkalising agent in place of lime by mixing 9 volumes of raw-juice with one volume of milk of lime of 15° Be and allowing the reaction time of 5 minutes. 10% of the cold juice is mixed with all the lime dose and the saccharate formed is added to preheated remaining 90% juice. The resultant treated juice at pH 7.6 is heated to boiling and sent to settlers. This saccharate method was found
to yield clearer juice with higher removal of impurities like wax as compared to conventional lime addition procedure.³

4.2. **Rabe system**—This system developed in South Africa for elimination of starch, involves one more stage than the conventional defecation methods. To the limed and heated juice (65°C) flocculant is added in a mixer. The treated juice is held for six minutes in the mixer and vacuum is applied to the mixer. The air bubbles rising upwards carry precipitate which is removed in the form of scum. The clear juice withdrawn from below is heated to boiling and sent to settler. The principle underlying this method is the removal of starch below 67°C at which the starch goes into solution.

4.3. **Compound clarification**—In this system primary juice of high brix and purity and the secondary juice which is of lower brix and purity are separately treated. The treated juices are sent to separate subsiders. The clear juice from secondary juice clarifier is sent to primary juice treatment tank while the mud from primary juice subsider is mixed with secondary juice. In the ultimate analysis, the secondary juice is twice treated with clarificants and only clear juice from primary juice clarifier is sent for further processing. Main advantages of compound clarification are

(a) better elimination of colloids and other nonsugars and

(b) improved filterability of muds from secondary clarifier as compared to simple clarification process.

5. **pH CONTROL**

In factories following colourimetric method of pH control the operator checks off and on pH of juice from the treatment tank with pH paper (Bromothymol blue or phenol red indicators) and at regular intervals finds out pH with the colour comparator. In some factories this system of control is supplemented with pH estimation in laboratory by electrometric method. The modern practice however is to control dose of lime by pH controller based on electrometric pH determination employing glass calomel electrode system, which gives more accurate pH reading than the colourimetric method.

6. **REACTIONS IN LIME DEFECATION**

6.1. **Phosphate precipitate**—As stated earlier phosphate precipitation after reaction with lime is the main reaction responsible for juice clarification. The reactions between lime and phosphates take time for reaching equilibrium and are rendered more complex in nature in juice due to the presence of organic acids, proteins and inorganic compounds. Lime reacts with soluble phosphates as follows—

(i) \( \text{Ca}^{2+} + \text{HPO}_4^{2-} \rightarrow \text{CaHPO}_4 \)

(ii) \( 3\text{Ca}^{2+} + 2\text{PO}_4^{3-} \rightarrow \text{Ca}_3(\text{PO}_4)_2 \)

The tricalcium phosphate is transformed into insoluble hydroxyapatite with drop in pH of juice. Formation of hydroxyapatite is accelerated by high temperature and optimum
conditions for formation of phosphate precipitate are a. pH of 7.5-8 and b. heating to 100°C.

Cane juice contains phosphates both in ionic and nonionic form in varying amounts from 50-200 mgms per litre and the optimum level of P$_2$O$_5$ of 300 ppm. is made up, in case of deficiency by adding soluble inorganic phosphate for proper clarification. However, Perk lays greater emphasis on the ratio of P$_2$O$_5$ to the contents of SiO$_2$, sesquioxides and HCL insoluble inorganic salts in preference to only maintaining the level of P$_2$O$_5$. He further states that when the ratio

\[
P_2O_5
\]

\[\text{SiO}_2 + \text{Fe}_2 + \text{Al}_2 \text{O}_3 + \text{HCl insoluble matter}\]

exceeds 0.25, the settling is fast and juice clearer, while for ratio between 0.15 to 0.25 the mud settling will be in order but the clear juice will lack clarity. If this ratio is below 0.15 the mud volume will be very high and supernatant clarified juice will not be clear. When the above ratio far exceeds 0.25 the mud volume will be high but the juice will be clear.\(^6\)

According to Payne\(^7\) the tests in Hawaii have shown that the inorganic phosphate added to juice is 99% precipitated at 8.5 pH while the phosphorus present in the plant is only 90% precipitated. For a physiologically old or sour cane this percentage is still less i.e. 75% and 65% respectively. Some organic phosphate present in cane is also precipitated. Among the organic phosphates, the hexose phosphates decompose at high temperature Honig points out that these organic phosphates are present to the extent of 20-60 mgm P$_2$O$_5$ per litre. They generate acidity on decomposition.\(^9\) Honig has suggested that the inorganic phosphate in clarified juice should not be less than 10 mgm per litre since such low levels result from overliming which increases nonsugar content of clarified juice.\(^8\)

6.2. pH—Low pH i.e. below 7.0 coupled with high temperature bring about inversion of sucrose and studies on pH by D.P. Kulkarni et al\(^10\) have shown the drop in pH at operating temperature (70°C) in the case of mixed juice from room temperature is 0.1 while in the case of clear juice from defecation process the pH at 90°C is lower by 0.45 - 0.65 from that at room temperature. It is thus important that pH at the operating temperature should be estimated to avoid risk of inversion and pH in clarifier where the clear juice remains at 90°-95°C for 3 to 3½ hrs. has to be maintained keeping mis fact into account. Likewise with mixed juice, phosphoric acid addition beyond certain limit results in inversion of sucrose. The safe limit of P$_2$O$_5$ addition has therefore to be determined only after experimentation on increase in R.S./pol ratio as shown by the work of D.P. Kulkarni and others."

As stated earlier formation of hydroxy apatite 2Ca$_3$ (P$_4$O$_{12}$) Ca(OH)$_2$ from Ca$_3$(P$_4$O$_{12}$)$_2$ i.e. tricalcium phosphate explains drop in pH from limed juice and the clear juice by 0.2-0.4. Other reactions responsible for generation of acidity are."

(a) The proteins on longer contact with heat generate amino acids.

(b) Gums and pectins also form complex organic acids known as uronic acids.

(c) reducing sugars under influence of heat and alkali get decomposed into organic
acids. Normally in defecation 2-4% reducing sugars undergo destruction. Even improperly slaked lime added to raw juice can cause pockets of local alkalinity in the clarifier and result in reducing sugar destruction.

7. EFFECTS OF DEFECATION

Studies on defecation conducted by D.P. Kulkarni in Deccan Sugar Factories where juice was limed to pH 7.4 have shown that\textsuperscript{13}:

(a) the apparent purity rise of 0.8 was observed while the sucrose purity rise was around 0.5 unit.

(b) The reducing sugars distinction of 3-5% was noticed.

(c) CaO content rise in clarification i.e. from raw-juice to clear juice was to the extent of 200-300 mgms/litre due to—

(i) neutralisation of free acids in juice,

(ii) reaction of lime with the organic acids formed during clarification. Moreover CaO content in clear juice rises as the pH of limed juice is raised.

(d) Work on colour by the author showed no removal of colour.\textsuperscript{14} The above observations relate to conditions in Deccan Sugar Industry of India, where the cane quality is reasonably good.

(e) In Hawaii raw-juice liming to high pH viz. 8.5 has been found to reduce aconitic acid as calcium aconitate in filter cake whereas in Louisiana little or no aconitic acid removal has been observed. According to Honig 20% $S\textsubscript{0}$\textsubscript{4} is removed at normal pH of clear juice.\textsuperscript{15} Potassium and sodium remain unchanged during defecation but iron and alumina i.e. $Fe_2O_3$ and $Al_2O_3$ are removed to a considerable extent when juices are limed to 8.0 pH.

(f) Proteins are removed with precipitate calcium phosphate to the extent of 80% with normal pH of clear juice. Waxes are removed to a large extent in filter mud and gums which are a complex mixture of hemicellulose, pentosans and some hexosans are partially eliminated. Reversible colloids consisting of gummy substance low in ash persist through the process but the irreversible colloids generally high in mineral matter are largely precipitated.

8. EQUIPMENT

The entire process of Defecation involves following stages—

(i) Preheating in a juice heater,

(ii) continuous lime treatment.

(iii) final juice heating
(iv) settling of precipitate and removal of clear juice as well as mud in a continuous clarifier.

(v) filtration of muds.

The mechanical and design details of different equipment required for these operations are described in separate section. However certain important points to be borne in mind, concerning the lime defecation of juice during operation are as under—

(a) Preheating of juice before liming—Perk\textsuperscript{16} states that when juices contain high reducing sugars, with a ratio of 10% or higher R.S./sucrose, the juice prior to liming should be heated to 50°C obviously to minimise formation of undesirable products of decomposition of reducing sugars while if the ratio is below five percent, the juice may be heated to 70°C. In general it may be stated that the proper temperature of primary heating has to be decided on the basis of the percentage of reducing sugars in raw juice since destruction of reducing sugars increases sucrose loss in molasses.

(b) Mixing of lime with juice has to be thorough and Baikow favours contact time of 15-20 minutes as essential.\textsuperscript{7} The treatment tank stirrer should not have speed exceeding 60 rpm. so as to provide gentle stirring and avoid breaking of floes.

(c) With automatic pH control system it is preferable to allow major portion of lime to be added continuously in proportion to the raw juice while adding the requisite small amount of lime through the pH regulator. This helps reduce strain on the pH controller and ensures better control of pH.

(d) Along with good pH control temperature control has to be precise in both stages of heating. In the secondary heaters, the limed juice should be heated to 101°-103°C so that the occluded gases are eliminated through the flash tank along with vapour before the juice enters the clarifier. The floes of calcium phosphate should not be allowed to be broken during pumping.

(e) Longer retention of hot clarified juice in the clarifier results in destruction of sucrose, glucose and fructose. During long periodical shut down, commonly termed as cleaning day the juice temperature, purity and pH drop gradually. Baikow recommends addition of soda ash for 3-4 hrs. before shut down for raising the pH instead of lime to prevent colour formation and purity drop. According to him, with soda ash addition purity of clarifier juice remains practically unchanged,\textsuperscript{18}

(f) The muddy filtrates from the filter are returned invariably to weighed raw juice receiving tank. They are usually of lower purity than clear juice and separate treatment of these filtrates would improve the overall performance of clarification station. However, no method of separate disposal of filtrates has found wide acceptance on account of the additional investment on machinery required.

(g) In the process of sugar manufacture it is extremely important to ensure that sucrose is not decomposed at any stage of manufacture similarly reducing sugars have also to be preserved as they—

   (a) increase more sucrose to be recovered in molasses,
(b) form decomposition products which increase molasses quantity and also colour.

As stated earlier sucrose is sensitive to low pH while reducing sugars i.e. glucose and fructose are stable at low pH but are destroyed under alkaline (pH > 7.0) conditions. Time and temperature play an important role in destruction of sucrose and reducing sugars in that the decomposition is a function of both time and temperature. Thus in clarification if juice is heated to high temperature the duration of contact with heat has to be minimum Neutral condition i.e. pH 7.0 is ideal and in case of any deviations from this if essential, the time element must be taken care of.
REFERENCES

3. Ibid p. 543
5. Ibid p. 405.
 TABLE I  

 COMPOSITION OF MIXED JUICE  

3. Reducing sugars .......0.4—1.0%.  
4. Ash ............0.4—0.7%.  
5. CaO mgms/litre .......600-800.  
6. P₂O₅ mgms/litre .......60-300.  
7. N₂ ...........0.03-0.04%.  
8. pH ...........5.2-5.4.
<table>
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<tr>
<th>Degree Beuame</th>
<th>Density</th>
<th>Grams CaO per litre</th>
<th>CaO percentage by weight</th>
<th>Degrees Beuame</th>
<th>Density</th>
<th>Grams CaO per litre</th>
<th>CaO percentage by weight</th>
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Table 2 Contd.
FACTORS TO CONVERT MILK OF LIME OF 8-26° BE
INTO MILK OF LIME OF 15° BE AT 15°C

<table>
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<th>Degrees Be'</th>
<th>Conversion Factor</th>
<th>Degrees Be'</th>
<th>Conversion Factor</th>
<th>Degrees Be'</th>
<th>Conversion Factor</th>
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<td>1.3859</td>
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</table>

* This table is correct for 15°C, but can, for practical purposes, also be used at other temperatures.

(From 'Principles of Sugar Technology' Ed. PHortig 1950 p. 382)
PART III
SULPHITATION PROCESS

1. INTRODUCTION

Purification of juice employing sulphur dioxide and lime is termed as sulphitation. This process first invented in European beet sugar industry and later introduced in Java by end of the Nineteenth Century was operating successfully in that country before the 2nd World War, when the Java sugar industry was a model for the other cane sugar industries of the world, on account of the innovations introduced, the research work carried out and the technological advances achieved. Cane juice sulphitation was introduced after carbonation had been established, for production of plantation white sugar, since it possessed some special advantages in respect of lime consumption, ease of operation, equipment required etc.

Almost 85-90% of the white crystal sugar produced by vacuum pan sugar industry in India is manufactured by sulphitation process of clarification. Sulphitation is now widely practised in the Khandsari industry in our country for production of crystal sugar by open pan boiling. India is the only sugar producing country employing sulphitation on an extensive scale for manufacture of plantation white sugar. It needs to be emphasised that sulphitation is practised for production of white sugar while simple lime defecation is resorted to in the manufacture of raw sugar for export.

In a recent development in Hawaii, juice sulphitation had been found to be effective in overcoming some of the technological problems created by the new process of cane diffusion, relating to the quality of raw sugar produced.

In the initial stages, sulphur dioxide was used to neutralise the excess lime added to cold juice which was later boiled and the clear juice obtained after subsidation of treated juice and filtration of mud. An important landmark in the technological development of this process was the simultaneous liming and sulphitation of heated raw juice proposed by Harloff in 1912. Yet another significant improvement in this process was achieved by Honig and Khainovsky in 1926 by introduction of pH measurement in sugar manufacture, particularly in cane juice clarification.

Out of the two processes employed for production of direct consumption white sugar viz., carbonation and sulphitation the latter offers wide scope for variations in respect of sequence of additions of lime and sulphur dioxide. The lime requirement of sulphitation is nearly one tenth that of carbonation but 1.5 to 1.8 times that for defecation. The sugar produced by sulphitation is inferior in whiteness to the carbonation sugar but has better keeping quality from the point of colour development, than the latter as per experience of some sugar mills in India. Moreover sulphitation lends itself well to a high degree of automation and mechanisation and is comparatively simple for control and flexible for operation.
2. CHEMISTRY OF SULPHUR DIOXIDE:

2.1. Sulphur occurs as element in the USA, Sicily and to a smaller extent in Japan, Chile and France. Sulphur also occurs in abundance in combined form as sulphides of lead (Gelena) iron (FeS$_2$ or iron pyrites) Zinc and Copper. As sulphate, gypsum or calcium sulphate is of wide occurrence. The chief use of sulphur is for the manufacture of sulphuric acid, one of the most important chemicals used in various industries. Elemental sulphur is imported in our country for use in sugar manufacture and other industries. Sulphur obtained can be of 99.9% purity. The sulphur to be used in sugar manufacture must be free from Arsenic, Selenium and Tellurium which belong to the same group (VI) in the periodic table.

2.2. Properties—Sulphur has an atomic weight of 32.06 and melts at 113°C. It vapourises at 444°C when heated out of contact with air. On account of its self sustained burning characteristic a mass of pure sulphur once ignited burns completely in air. In fact in one simple practical test a small quantity of sulphur to be used in factory is ignited in a silica dish and if the entire mass is burnt out in air the quality of sulphur is considered satisfactory. Presence of impurities is indicated by formation of a dark layer on the surface which hinders combustion by restricting supply of oxygen (i.e. air).

2.3. Sulphur dioxide—Combustion of sulphur in a current of air generates sulphur dioxide S0$_2$. When sulphur is heated in air it first melts and at about 363°C burns with blue flame producing S0$_2$ and traces of SO$_3$.

\[ S + O_2 \rightarrow SO_2 + 2217 \text{ kcal/kg} \]

Sulphur dioxide is a colourless gas 2.264 times heavier than air and possess an obnoxious smell. It is a poisonous gas. It can be liquified under pressure the liquid boiling at -10°C. Molecular weight of SO$_2$ is 64.06. In the presence of moisture SO$_2$ is oxidised to SO$_3$ during the process of combustion of sulphur.

Sulphur dioxide is highly soluble in water, 45 volumes being soluble in one volume of water. However, a saturated solution of sulphur dioxide in water when boiled expels SO$_2$ completely.

It combines with water to form sulphurous acid.

\[ H_2O + SO_2 \rightarrow H_2SO_3 \]

If the SO$_2$ contains traces of SO$_3$ some sulphuric acid is formed

\[ H_2O + SO_3 \rightarrow H_2SO_4 \]

The sulphurous acid is dibasic and forms both normal and acid salts.

\[ H_2SO_3 \rightarrow H^+ + HSO_3^- \text{Hydrosulphiteion} \]

\[ H_2SO_3 \rightarrow 2H^+ + SO_3^- \text{ Sulphite ion} \]

The first i.e. hydrosulphite is acid salt while the sulphite is the normal salt. Sulphurous acid or sulphur dioxide in solution possesses reducing action and acts as electron donor in conjunction with water as follows—
H₂O + SO₂ → 2H⁺ + SO₃²⁻
SO₃²⁻ + H₂O → SO₄²⁻ + 2H⁺ + 2e⁻

The sulphite ion is oxidised to sulphate ion SO₄²⁻.

An important reaction from the point of sugar manufacture is reduction of coloured ferric compounds. Brown colour of iron compound is removed by reducing ferric salts to ferrous.

2Fe³⁺ + 2e⁻ → 3Fe²⁺

SO₂ gas is highly soluble in water, the solubility being lowered with increase in temperature as shown in the following table.

### TABLE 1

<table>
<thead>
<tr>
<th>Temp. C</th>
<th>20</th>
<th>40</th>
<th>50</th>
<th>70</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂ % by weight</td>
<td>8.6</td>
<td>6.1</td>
<td>4.9</td>
<td>2.6</td>
<td>0.9</td>
<td>0.1</td>
</tr>
</tbody>
</table>

SO₂ on combining with water molecule forms H₂SO₃ which is a weak acid. The electrolytic dissociation of this dibasic acid takes place in two ways and the two dissociation constants can be expressed as

\[ K_1 = \frac{(H^+)(HSO_3^-)}{(H_2SO_3)} \quad \text{&} \quad K_2 = \frac{(H^+)(SO_3^2-)}{HSO_3} \]

in accordance with following two steps

\[ H_2SO_3 \rightleftharpoons H^+ + HSO_3^- \]
\[ HSO_3^- \rightleftharpoons H^+ + SO_3^{2-} \]

\( K_1 \) & \( K_2 \) are dependent on pH of solutions.

Marches³ has presented graphs showing variations in dissociation of sulphurous acid with pH of aqueous solution at 18°C. From the curves in this graph it is obvious that above 9.5 pH no bisulphite ions are present while below this pH values sulphite ion content gradually comes down upto pH 4.5. Below this pH only bisulphite ions are formed.

According to Zerban the sulphite ions block the carbonyl function of reducing sugars and prevent their combining with amino acids to form melanoidins which are coloured compounds. Similarly sulphite ions also retard formation of caramel from reducing sugars.

At pH below 6.0, SO₂ forms insoluble complex \([R_2O₃(SiO₂)_n]\) with Al₂O₃ and Fe₂O₃.

SO₂ converts the organic acid salts of calcium into insoluble calcium sulphite releasing free organic acids in the sulphitation of syrup.
3. PREPARATION OF LIME SOLUTION

3.1. Manufacture of lime—Calcium carbonate when heated to 550°C starts decomposing to form calcium oxide. In a closed system at a certain pressure of carbon dioxide known as dissociation pressure the reaction stops. This pressure corresponds to definite temperatures as follows—

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>Pressure mm Hg (at 0°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>2.35</td>
</tr>
<tr>
<td>600</td>
<td>25.0</td>
</tr>
<tr>
<td>700</td>
<td>168</td>
</tr>
<tr>
<td>800</td>
<td>773</td>
</tr>
<tr>
<td>900</td>
<td>1490</td>
</tr>
</tbody>
</table>

\[
\text{CaCO}_3 \rightleftharpoons \text{CaO} + \text{CO}_2 \quad \Delta H = -42.5 \text{ Kcal.}
\]

The \( \text{CO}_2 \) has to be removed for completion of reaction and production of CaO. Longer retention in Kiln at high temperature yields dead burnt lime of 25% higher density than normal lime. The dead burnt lime takes time to slake properly. Presence of high amounts of silica and acidic impurities favours formation of dead burnt lime.

Many sulphitation factories in India have installed lime Kilns and produce the lime required for the factory. A factory with a crushing capacity of 1500-2000 Tonnes cane per day will require at the rate of 0.2 to 0.25% lime on cane, nearly 4 tonnes lime per day for clarification only. Unlike in carbonation plants, lime kilns in sulphitation factories give out the carbon dioxide into the atmosphere and employ coal for burning. The coal usually available to Indian Sugar factories for burning limestone is high in ash content and the ratio of coal to limestone is around 30-35%. Designs of continuous working lime kilns are available for different capacities and it is advantageous to install lime Kiln and produce lime at the factory from the point of view of the supplying fresh and good quality lime to clarification house of the factory. Attempts have been made to use bagasse as fuel and study the technical feasibility of the same. However, thorough pilot plant trials are required to be carried out.

Theoretical yield of lime from calcination of lime stone is 56%, though in actual practice 45-50% yields of handpicked good lime are obtained.

3.3. Calcium oxide is a very reactive compound and is a strong base. It combines with water evolving heat and produces calcium hydroxide.

\[
\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + 15.54 \text{ Kcal.}
\]

The reaction is strongly exothermic.

Calcium hydroxide absorbs carbon dioxide from air to form calcium carbonate.

\[
\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}
\]

The lime therefore has to be stored out of contact with air and as far as possible used soon after it is produced. It also becomes an ideal drying chemical for air used for \( \text{SO}_2 \) preparation on account of its affinity for water. In fact a practical test for properly burnt lime consists in adding small quantity of water to lime when the lumps of CaO crumble to form white powder with hissing. Gradual water addition will first result in powder
formation and later with formation of paste which ultimately gives, with sufficient quantity of water, white suspension known as milk of lime. Slaked lime is sparingly soluble in water, solubility being 0.12 percent at room temperature, which is reduced to 0.08 per cent at 65°C. The following table gives CaO content of milk of lime at different brixes.

<table>
<thead>
<tr>
<th>Brix</th>
<th>Gram CaO/1000ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4</td>
<td>26</td>
</tr>
<tr>
<td>7.2</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>46</td>
</tr>
<tr>
<td>10.8</td>
<td>56</td>
</tr>
<tr>
<td>12.6</td>
<td>65</td>
</tr>
<tr>
<td>14.4</td>
<td>75</td>
</tr>
<tr>
<td>18</td>
<td>94</td>
</tr>
<tr>
<td>21.7</td>
<td>115</td>
</tr>
<tr>
<td>27.2</td>
<td>148</td>
</tr>
</tbody>
</table>

(from Cane sugar Handbook by Spencer & Meade Edn.8 p. 701).

This table would serve for rough guidance and it should be possible to find out the quantity of lime being used from the brix of the milk of lime during running.

Lime forms saccharate with sucrose as follows—

(a) Monocalcium saccharate
(b) Dicalcium saccharate
(c) Tricalcium saccharate

Mono and dicalcium saccharates are soluble in water while tricalcium saccharate is insoluble. A 15% sucrose solution when saturated with lime will contain 18.5% lime. The solubility of lime in sucrose solution decreases with temperature as revealed by the data in following table relating to 13% sucrose solution.

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>gm of CaO dissolved in 1 Kg. of solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>14.8</td>
</tr>
<tr>
<td>70</td>
<td>3.0</td>
</tr>
<tr>
<td>100</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Similarly solubility of lime in water also decreases with rise in temperature.

3.4. Dispersion of calcium hydroxide is of paramount importance in as much as the reactivity of calcium hydroxide in juice depends on the dissolved part of calcium hydroxide and the rate at which it goes into solution during the course of reaction with acid in the juice. Both these are dependent on the degree of dispersion of calcium hydroxide particles. Thus higher the dispersion, greater will be the reactive character of lime. The dispersion is determined by the lime quality as also the freshness of lime solution. A good quality lime, slaked in hot water gives a solution with high dispersion. A freshly prepared milk of lime possesses good dispersion but after some time the small particles coalesce to form bigger aggregates with reduction in reactivity. It is thus advisable to use freshly prepared lime during clarification.
3.5. Sugar mills which do not produce lime by burning of limestone at their factories buy either lime in lumps or hydrated lime in powder form. Hydrated lime is packed in polythene or tough paper bags while lime lumps are supplied either in polythene lined gunny bags or cardboard drums. The hydrated lime is a slaked lime i.e. Calcium hydroxide while the lumps of quicklime are calcium oxide. Yet another type of lime supply from market may be in the form of powdered quicklime, separated by air floatation. In USA good quality of powdered quicklime may even contain 99% CaO and pass through 300 mesh screen. In whatever form lime is purchased it is very important to store it out of contact with air until it is used in process. Thus the packing must necessarily be perfect without any damage occurring to containers. A regular check on quality of lime by carrying out detailed analysis is absolutely essential.

4. REACTIONS IN SULPHITATION

4.1. In sulphitation the lime reacts with sulphurous acid forming calcium sulphite as follows—

\[
\begin{align*}
\text{SO}_2 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{SO}_3 \\
\text{Ca(OH)}_2 + \text{H}_2\text{SO}_3 & \rightarrow \text{CaSO}_3 + 2\text{H}_2\text{O}
\end{align*}
\]

If excess of SO\(_2\) is passed into solution, pH is lowered and more HS\(_3\) ions go into solution. The SO\(_3\) ion concentration gradually goes down with the eventual formation of calcium bisulphite which is soluble.

\[
\text{CaSO}_3 + \text{H}_2\text{SO}_3 \rightarrow \text{Ca(HSO}_3\text{)}_2
\]

In sulphitation it is desirable to precipitate out as much calcium sulphite as possible though a certain amount of it corresponding to the solubility product of CaSO\(_3\) under operating conditions, will remain in solution. Solubility of calcium sulphite in sugar solutions and water has been studied previously and Van Der Linden has stated that—

(a) CaSO\(_3\) is more soluble in sugar solution than in water.

(b) CaS03 is sparingly soluble in water

(c) in the presence of CaS04 the solubility of CaS03 in sugar solution is reduced\(^3\).

The CaSO\(_3\) is more soluble in cold juice than in hot juice, minimum solubility being observed at temperature exceeding 75\(^{\circ}\)C. Hence the significance of preheating of raw juice to 70\(^{\circ}\)-75\(^{\circ}\)C before it is sent to sulphitation reaction tanks. Cold sulphitation will result in deposition of calcium sulphite scale in juice heaters.

For good filterability coarse aggregates of CaSO\(_3\) should be formed, which is achieved by maintaining low concentration of CaO and SO\(_3\) ions.

4.2. Farnell's\(^4\) studies on the precipitation of CaSO\(_3\) in sugar solutions in the presence of colloids lead to following conclusions.

(i) Complete precipitation requires long time and temperature up to 100\(^{\circ}\)C and absence of colloids.
(ii) Presence of colloids retards precipitation of CaSO$_3$ and reduces the size of clusters of crossed needles of CaSO$_3$ $\cdot$ 2H$_2$O.

(Hi) A dilute solution of calcium bisulfite on heating up to 100°C does not form CaSO$_3$ with liberation of SO$_2$.

(iv) Precipitation of CaSO$_3$ is complete at higher pH such as 7.6 to 7.8.

In practice high pH and high temperature are deleterious to the reducing sugars which get decomposed under these conditions to form colouring matter. Hence it is necessary to maintain pH which would be conducive to maximum completion of CaSO$_3$ precipitate without destruction of reducing sugars. A pH of 7.2 to 7.3 is maintained at the sulphitation station so as to obtain clear juice of 7.0 pH which represents optimum condition.

4.3. Effect of pH—In clarification, most important point to be kept in mind is the effect of various reactions on the sucrose and reducing sugars which have to be preserved intact and thus it is relevant to see the effects of variations of temperature and pH on the same.

4.3.1. Sucrose—Sucrose is fairly stable at high pH, but undergoes decomposition when subjected to low pH. Sucrose is hydrolysed at low pH into reducing sugars following the reaction.

\[ C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_2O_6 \]

\[ \text{glucose} \quad \text{levulose} \]

This reaction is catalysed by hydrogen ions and the rate of hydrolysis is higher, higher the temperature and lower the pH. Thus pH below 7.0 is to be avoided in all the treatments of juice in clarification to prevent inversion since the above reaction is irreversible.

4.3.2. Reducing sugars—The juices normally contain 0.5 to 1% reducing sugars which play vital role in determining the exhaustion potential of molasses in the final phase of crystallisation. Reducing sugars also have to be kept intact to obtain maximum crystallisation of sucrose in final boiling.

Reducing sugars are more reactive than the sucrose/ and unlike the latter are unstable at high pH. High temperature accelerates this decomposition. Out of these two hexoses, fructose is more sensitive to alkaline conditions and is decomposed more rapidly than glucose. When reducing sugars are reacted upon by alkali, fructose is destroyed first while more fructose is formed from glucose in accordance with Lobry De Bruyn Van Ekenstein transformation, whereby equilibrium of glucose and fructose is maintained in alkaline medium.

The decomposition of reducing sugars in alkaline condition results in formation of lactic, gluconic, saccharanic and oxalic and other organic acids which combine with lime to form calcium salts. While salts like calcium oxalate and calcium lactate are stable some other organic acid salts decompose into acids under influence of heat. Under mild alkaline condition slightly coloured acids like lactic acid are formed. At higher
temperatures, the acids formed, combine with lime to form coloured compounds. Thus the decomposition of reducing sugars has to be avoided for following reasons—

(i) Organic acids are formed which increase calcium content of juices,

(ii) The salts of organic acids increase scaling of evaporator,

(iii) Dark coloured compounds are formed which increase colour content of juice,

(iv) Exhaustibility of molasses is adversely affected.

The conditions under which sucrose remains stable are contrary to those for reducing sugars and therefore as far as possible pH close to 7.0 should be maintained and the time of contact at high or low pH should be minimal. Particularly at high temperatures minimum time of reaction is essential when pH deviates from 7.0 either way.

4.4. Colloids—Colloids are of two types hydrophobic and hydrophilic. Precipitation of colloids in cane juice is important in so far as they contribute to viscosity in sugar boiling and affect the exhaustibility of molasses. The hydrophobic colloids are electrically charged and do not get precipitated until their charge is neutralised. Neutralisation of their charge which results in floc formation can be accomplished by adsorption on oppositely charged precipitates. Cane juice colloids are mostly negatively charged and are adsorbed on tricalcium phosphate and calcium sulphite precipitates.

Hydrophilic colloids in cane juice consisting of organic compounds like hemicelluloses, nitrogenous compounds etc. owe their stability to the water molecule attached to the colloidal particles and can be precipitated by heating.

Again some colloids are reversible in nature i.e. they are peptised even after precipitation with change in conditions like pH. Calcium phosphate precipitate with large surface area is effective in adsorbing colloidal particles and it is very often observed that increase in phosphate does result in better clarity of juice. As the conditions with respect to isoelectric point of colloids are different for different types of colloids and conditions for precipitating all types of colloids cannot be fulfilled, the removal of colloids in sulphitation is around 30-40%.

5. S0₂ PREPARATION

5.1. Sulphur heated to 250°C is oxidised to sulphur dioxide with evolution of heat (2217 K cal/kg) which heats the sulphur in the burner and raises its temperature to the point of oxidation in the presence of air. The molten sulphur first is vaporised and the sulphur vapours in contact with air form sulphur dioxide. Vapour pressure of sulphur increases with temperature and unless sufficient air is supplied complete conversion of sulphur to sulphur dioxide is not possible. The mixture of sulphur dioxide and sulphur vapour when cooled will result in deposition of sulphur on the cool surface. This phenomenon is known as sublimation.

Secondly a small portion of sulphur dioxide is further oxidised to sulphur trioxide following the reaction \(2 \text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3\)
This reaction is exothermic and more \( \text{SO}_3 \) is in equilibrium at lower temperatures. As stated earlier \( \text{SO}_3 \) formation is catalysed by traces of water and iron oxide. \( \text{SO}_3 \) combines with water to form sulphuric acid \( \text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 \).

In view of the above considerations, cooling of the burner is necessary to avoid excessive rise of temperature by extracting heat from the burner. This is accomplished by circulating cold water over the top of the burner.

Second factor is supply of sufficient air for completion of \( \text{SO}_2 \) formation, since with inadequate oxygen sulphur vapour would remain unreacted and be carried with the gas.

The entire system should be designed taking into account—

(i) Conversion of sulphur into sulphur dioxide without any sulphur deposition.

(ii) Preventing \( \text{SO}_3 \) formation.

(iii) \( \text{SO}_2 \) percentage to be 12%-14% gas,

(iv) Production of \( \text{SO}_2 \) to meet the varying requirements of sulphitation.

5.1.1. The sulphur dioxide station comprising (a) burner, (b) cooler, (c) scrubber (d) air dryer and (e) air compressor is very often located in close vicinity of the lime station, usually on ground floor of the plant.

A sulphur stove, designed to work continuously is composed of three parts (1) sulphur melter (2) a chamber for molten sulphur and (3) the burner or the chamber where sulphur is converted into sulphur dioxide. All these are separated from each other by isolating plug type valves, the first two being provided with steam jackets for melting the sulphur and maintaining the same in molten state respectively. The chamber for molten sulphur serves as feeding chamber to the combustion chamber with which it is directly connected.

Steam of about 5 Kg/cm\(^2\) is supplied to the steam chambers which must be thoroughly lagged.

Usually the melter capacity is designed for a two hourly charge of solid sulphur. During \( \text{SO}_2 \) production when the level of sulphur in the combustion chamber is reduced, the melt from the feeding chamber is allowed to flow by opening the inter-connecting valve, care being taken that the valve between the charging hopper and feeding chamber is kept closed.

The charging and feeding hoppers are of mild steel construction and the valves are of C.I. (cast iron).

5.1.2. **Combustion Chamber**—This is of CI or MS construction, but lined from inside with refractory material. The air inlet is near the entry of sulphur melt, the \( \text{SO}_2 \) withdrawal being from the other end. Suitable baffle is fitted to prevent short circuiting of air. The burner is invariably provided with a slow moving stirrer (2 rpm) to break the film of impurities formed on molten sulphur and ensure positive contact of sulphur with oxygen. When the sulphur contains high impurities (> 0.1%) the stirrer has to be operated, whereas for sulphur with 99.9%, sulphur content the stirrer may be worked intermittently.
The area of combustion chamber is based on burning of 20-25 Kg. sulphur per m² per hour.

5.1.3. Coolers—The hot S0₂ gas produced (300°C) has to be cooled sufficiently and as a first step the top of combustion chamber is cooled by running cold water which extracts heat from the burner. Besides, the pipes between the burner and scrubber are provided with water jackets through which cold water is circulated. Length of pipes thus cooled is between 3 to 7 m. The temperature of hot water on the top of combustion chamber should be 50°-60°C. All the S0₂ piping is of C.I., ID being 100-125 mm for a standard normal plant (1250-2000 t/day).

5.1.4. Scrubber—The SO₂ gas from the coolers enters the scrubber which is a cylindrical vessel provided with a false bottom and packed with refractory bricks. The scrubber is of cast iron construction and fitted with a water jacket on the outside for further cooling of the gas. Whatever sulphur is carried by the S0₂ gas as a result of sublimation, is deposited in the scrubber and traces of sulphur trioxide formed are converted into sulphur dioxide. The sulphur dioxide gas emerging from scrubber should not have temperature higher than 50°C-60°C The S0₂ gas is conveyed by C.I. pipes and fittings. The valves installed in sulphur dioxide lines are C.I. Saunders valves with rubber diaphragm.

5.2. Air Dryer—As explained earlier moisture in air going to sulphur burner converts S0₂ into S0₃ which forms sulphuric acid in juice and leads to formation of Calcium sulphate which is highly soluble in juice as compared to calcium sulphite. In order to eliminate the water in air one way is to compress the air and cool it. In practice compressed air is used but it is not cooled. An effective method of removing moisture in air is to connect the suction of compressor to an air-dryer which is constructed of M.S. and consists of a number of perforated trays on which lime lumps are placed. The dryer box has to be air tight and the lime is changed once in 8 to 12 hours of operation. For every 100 cum of air used for S0₂ generation about 30-35 Kgs. of lime are required. The trays are placed one over the other and are removable, the top being covered by cotton waste and wirenetting to prevent lime powder entering the compressor. In spite of these precautions fine lime powder is found to deposit on compressor valves which have to be cleaned once a week.

5.3. Other types of Burners—The sulphur stove described earlier operates at pressures higher than the atmosphere viz. 0.5 Kg/cm² but there exists another system in which the sulphur burning takes place at reduced pressure, by aspirating air through the stove. In one method an airblower is interposed between the sulphitation vessel and the scrubber, thereby suction being created in the sulphur burner. In yet another system known as Quarez apparatus developed in Java which also operates on similar principle, air passed over quicklime enters the sulphur burner and an ejector forces it into the sulphitation reaction tank. Suitable baffles ensure thorough contact of air with sulphur. The aspirator fitted at the sulphitation tank sucks the air from the burner through scrubber and cooler as required in any S0₂ generating system.

Yet another system employs rotary sulphur furnaces in which air is admitted in the furnace by induced draft. The burner is a horizontal cylinder with cone shaped cast iron ends, revolving slowly at about 1/2 rpm. Sulphur is fed at the mouth while air is
admitted at the front end by suction created in the sulphitation tower. Rotary movement ensures disturbing the film of impurities formed on the surface of molten sulphur thereby improving efficiency of combustion. The gas from rotary burner enters a combustion chamber which is usually lined with refractory bricks, wherein unburnt sulphur is completely oxidised.

5.4. Special Characteristics of Different Systems——

1. In sulphur stoves operating under pressure——
   
   (a) leaks are common from joints, valves and other fittings,
   
   (b) chances of sublimation are more
   
   (c) automatic feeding may not operate properly,
   
   (d) combustion cannot be seen,
   
   (e) if operated carefully the system works well and is established in our industry.

2. In sulphur burners working under reduced pressure
   
   (a) leaks are absent
   
   (b) feeding can be regulated
   
   (c) combustion can be observed
   
   (d) low power consumption is obtained as compared to the pressure system.
   
   (e) disadvantage is the method of aspiration and if blower is used the material of construction should resist corrosion due to SO$_2$

It is desirable to introduce in the sugar industry new design of sulphur burners in view of the shortcomings of the present ones which do not lend themselves to automatic and continuous operations.

Sulphur stoves operating with complete automatic controls, to meet the requirements of rate of juice flow into sulphitation tanks, should be installed.

5.5. Capacities——

   (a) Sulphur burning area required is calculated on the basis of 20 to 25 Kg. of sulphur per m$^2$ of area,

   (b) Air compressor capacity required is 6.24 m$^3$ of air per Kg of sulphur burnt, per hour.

It is desirable to install separate sulphur stoves for juice and syrup sulphitation and keep one unit as standby.

Sulphur combines with oxygen of air forming sulphur dioxide.

\[
S + O_2 \rightarrow SO_2
\]

\[
32 + 2(16) \rightarrow 64
\]

1 Kg. of sulphur would thus theoretically require one Kg. of O$_2$ or 100/23.15 Kgs. of air i.e. approx. 4.3 times the air by weight. This corresponds to a supply of 3.34 m$^3$ of air per Kg.
of sulphur. Allowing for some excess air for completion of conversion of sulphur to sulphur dioxide 6.24 cu.m. of air should be adequate for burning one kg. sulphur.

The $SO_2$ content of the gas from the sulphur burner under normal operating conditions should be 12 to 14% taking into account the above excess air, as against the theoretical percentage of about 21.0. $SO_2$ estimation by the standard procedure involving absorption of gas in N/10 iodine solution provides guidance regarding the excess air and the combustion.\(^5\)

5.6. Special precautions in $SO_2$ generation

1. The capacities of burners should be adequate. Larger areas of combustion can be reduced by blocking some portion of sulphur stove by means of refractory bricks. Larger capacities lead to higher sulphur consumption.

2. Compressor capacity should correspond to the peak rates of crushing envisaged.

3. Great care must be exercised in respect of air drying in the lime dryer.

4. Burner should not be overheated as it would lead to sublimation.

5. Manometer should be installed on the airline going to sulphur stove and its readings noted regularly.

6. Temperature gauges should be installed at the exist from (a) sulphur stove (b) gas outlet from scrubber.

7. $SO_2$ content in $SO_2$ pipelines should be estimated occasionally.

8. Sublimation results from abnormally high temperature in combustion chamber occasioned by
   (a) insufficient quantity of sulphur
   (b) inadequate air supply
   (c) less cooling water. These conditions have, therefore to be avoided.

6. LIME PREPARATION STATION

6.1. Lime—Lime station in a sugar mill comprises following sections for different functions given below—

(a) Rotary slaker: for slaking of lime,

(b) Desanding for removing grit & sand from slaked lime.

(c) Storage tanks for storing milk of lime.

(d) Lime pumps for pumping milk of lime to sulphitation tank.

6.2. Rotary slaker—This is a cylindrical M.S. drum revolving at about 6 rpm provided with baffles on the inside. The baffles consist of M.S. Strips concentric with the drum and forming a spiral which move the lime while at the same time allowing time for slaking.
Dry lime and water are fed at one end or at opposite ends while slaked lime flows out on to a screen. A suspended plate at the discharge end serves to remove the unslaked portions and grit.

The drive is provided by an electric motor through a reduction gear and sprocket while the driven rim is mounted on the drum.

Hot condensate should be used for two reasons, one is the high purity of water and second is the effective slaking obtained with hot water. Use of raw water would besides introducing soluble impurities, retard the slaking operation and is to be discouraged.

The milk of lime is discharged on a stationary coarse strainer. There are two ways in which the slaker can be operated on the basis of the direction of rotation.

(a) Cocurrent flow—The dry lime and water are fed at the feed end and flowing in the normal direction as guided by the baffles.

(b) Counter current flow—The lime and water feeding being at opposite ends, the system has counter current flow.

Counter current flow is claimed to achieve better elimination of grit and ensure better slaking of lime. Milk of lime of higher concentration can be obtained, the withdrawal of lime being at lime feeding end. Grit is eliminated at the other end, where water is added. Thus the lime of this end is very thin and lime accompanying grit is considerably reduced.

6.2. Degritting equipments—There are two different devices for eliminating the residual grit and sand

(i) classifier with screw conveyer,

(ii) classifier of rake type mechanism.

In a simple arrangements, the slaked lime from the lime slaker is discharged into an inclined semicylindrical gutter fitted with a screw conveyer which throws out the sand and grit, while lime overflows into the storage tank. The scroll revolves at slow speed.

In the other design of classifier the grit is removed by rake type mechanism.

6.3. The storage tanks are necessarily fitted with stirrers running at 8 to 10 rpm and box type strainers before the pumps. An overflow from lime dosing device at the sulphitation is led into the storage tanks.

The lime pump is always kept running as long as the sulphitation unit is in operation. The lime pumps are now a days of centrifugal open impeller type, with C.I. body and impeller. The lime pipe size should be calculated on the basis of a flow velocity of 1 m/sec.

The bearings of all these units should be of cast iron and not bronze.

The storage tank capacity should be adequate for atleast 8 hrs. operation and milk of lime of constant brix should always be supplied to sulphitation reaction vessels to facilitate maintaining a uniform lime dose. Thus factory should install two milk of lime storage tanks fitted with stirrers having individual or common drive.
It is desirable to allow two hours' time to ensure complete slaking, in tanks before the lime solution is used for clarification. At the same time too long delay in storage is also not desirable as aging of milk of lime results in formation of bigger particles. As for slaking for dilution also, hot condensates should be used.

In practice, out of the two storage tanks one contains high brix lime (20°-25°) while the other tank, from which the lime is pumped to sulphitation station contains the diluted milk of lime of 8°-12° Bx concentration which is found to be effective and convenient for automatic dosing. The overflow from the lime dosing device ensures continuous circulation. The first tank receives the lime from slaker and classifier while the latter one stores diluted milk of lime of desired brix, both the tanks being inter-connected with an isolating valve.

6.4. Davies\(^6\) on the basis of experience in Trinidad observes that soluble silica can be removed from lime by decantation, with reduced silica content in clear juice by 50%. However, this has not been commercially brought into practice in India.

Sieves have to be inserted at—

(a) Discharge from slaker

(b) in storage tanks.

These usually consist of perforated metal sheets with 3-5 mm opening as small opening leads to clogging of holes within a short time.

Besides, box strainers are interposed between the outlet of storage tank and the inlet of lime pump. All these screens need frequent cleaning. A hot water connection may also be provided at the suction of pump for removing settled lime and cleaning pipelines. When branches are provided for main pipelines, the branched pipe must be connected at the top of the main pipe to prevent choking.

6.5. To sum up, following precautions are important from the point of view of maintaining proper control on quality of milk of lime used in clarification.

1. The lime should be fresh and well burnt,
2. It should be slaked in hot condensates,
3. Slaked lime should be further made free from grit and sand,
4. Lime should be diluted with hot condensate to the desired brix and a constant concentration maintained in the case of lime solution going to clarification station.
5. Sieves should be provided at different points which should be constantly washed and cleaned as they get clogged soon.
6. Lime pump should be operated continuously with circulation of lime from lime dosing device, during mill operation.
7. It is desirable to install rotary slaker, a classifier system and storage tanks for lime solution.
6.6. Use of Saccharate—As pointed out earlier lime forms saccharates with sucrose and the saccharates thus formed are claimed to possess high reactivity and better clarifying properties than lime. Marches\(^7\) advocates use of 10-20% cold mixed juice for saccharate formation which can clarify the remaining 80-90% juice. Some workers have obtained greater wax elimination accompanied by higher mud volumes with saccharate addition. Experiments conducted in India have also indicated better results with saccharate, in cane juice sulphitation.\(^8\) However, detailed investigation is called for in this behalf and more positive data has to be collected in regard to its application in sulphitation.

7. SULPHITATION EQUIPMENT

7.1. The sulphitation apparatus for cane juice clarification is designed taking into account the following important factors.

1. Variation in lime and sulphur dioxide doses should be possible keeping in view the requirements of the juice for optimum clarification.

2. The reactants must be thoroughly mixed.

3. Mixing in the tank should be thorough so as to avoid formation of pockets of over alkalinity or over acidity.

4. The retention of juice in reaction vessels has to be 10-20 minutes for completion of reaction.

5. Capacity of the reaction vessels should be determined on the basis of retention time.

7.2. Batch sulphitation—This has become obsolete these days. Usually there are three MS tanks, each provided with S0\(_2\) connection and a lime dosing vessel attached as well as connected to it. The treatment vessels are fitted with mechanical stirrers and when one vessel is being filled, the other is being discharged while the third is receiving treatment of S0\(_2\) being bubbled at the bottom. After the required lime dose is fed and the desired pH of 7.2 - 7.3 is reached the S0\(_2\) valve is closed and the treated juice is ready to be discharged. Because of the human element involved in controlling the reactions during the batch operation the results of treatment are not uniform and properly controlled. Factories which converted their batch operations into continuous ones have obtained improved results\(^12\).

7.3. Continuous Sulphitation—

7.3.1. In continuous sulphiters a number of designs have been evolved in the past 50 years or so, based on following considerations.

1. Two reactions tanks, interconnected, are installed, juice entering in one, and leaving the other.

2. Usually stirrers are provided

3. The reactants are normally fed in one tank while the other tank serves for completion of reaction, or rectification of pH if required.
4. The total capacity of the equipment is based on juice retention of 10-20 min.

5. The flow of juice, lime and S0₂ have to be uninterrupted,

6. The gas distribution should generate small size S0₂ bubbles for efficiency of reaction.

7. Stirring and S0₂ bubbling should generate high circulation in the juice.

8. Lime used is of low brix (10°-15°) to facilitate quicker formation of CaS0₃ and maintenance of optimum pH.

Some features of important designs of the continuous sulphiters are described later. However, major components of system are (a) S0₂ destruction (b) lime dosing arrangement, (c) tank design (4) pH control, which need to be dealt with first.

7.3.2. S0₂ distribution—The aim in designing S0₂ distribution has to be to ensure maximum absorption of S0₂ and the existing designs could be classified as follows—

(i) In a simple arrangement the gas pipe is connected to the bottom of conical sulphitation tank, gas distribution being achieved by perforated plate placed over it. In one design the S0₂ and juice are led into the tank through the same pipe thus achieving presulphitation of a short duration. Baffles provided inside the tanks and stirrer should take care of circulation inside the sulphiter.

(ii) In one design a cast iron baffle is located over the gas entry from bottom of the tank which distributes the gas inside the juice mass thereby setting up a current. This arrangement aids circulation of juice in the tank while at the same time dividing the gas stream in a cylindrical path. A serrated cone is connected to the SO₂ gas pipe entering the tank.

(iii) In yet another design the S0₂ gas pipe enters the tank at the bottom and is connected to an inverted cone the top of which has perforations for distribution of gas or is covered with a perforated plate.

(iv) S0₂ can also be bubbled through a circular coil or a cross type distributor with large perforations.

An ideal distributor would be one that will bubble gas in finely divided state and will fulfill following requirements—

(i) It should be possible to clean the distributor easily if and when sublimation occurs.

(ii) The gas is divided into a number of streams with definite passages.

(iii) Size of gas bubbles is as small as possible for quick absorption.

In view of above a satisfactory distributor will consist of a pipe with enlarged opening or an inverted cone type. Covered with removable plate provided with holes large enough to resist choking. According to Marches 13 ten seconds contact is enough for gas to be absorbed completely when the juice pH is 7.4 - 8.3 and temperature is 75°C.

7.3.3. Lime Dosing—The lime must be fed into the tank in the area of maximum circulation preferably near the S0₂ gas inlet, without in any way disturbing the circulation of juice.
Thus in some designs the lime pipe is connected to the sulphitation tank at a suitable point at the bottom or top of the tank whereas in some sulphiters lime pipe enters the bulk of juice. In general if the lime feeding is at the top of the juice column, the juice withdrawal is from the lowermost point of the sulphiter and vice versa.

The lime proportioning devices presently used can be broadly classified into two categories (a) Mechanically operated (b) Electrically operated or with electronic controls.

As pointed out earlier the lime vessel receives milk of lime continuously, the overflow therefrom delivering the surplus lime back to the lime storage tank. The lime tank is divided into two compartments, one for receiving lime and the other for maintaining a constant level through which lime connection to sulphitation vessel is given and provided with an overflow pipe. The inlet can be from bottom. As regards the proportioning of lime or regulating its flow into the tanks a number of variants are adopted based on (a) continuous feeding (b) manual regulation of dose. Some of these are described below.

(1) Lime nozzle—In this nozzle an adjustable conical pin is fitted and the flow of milk of lime can be varied according to the position of pin, whereby the opening of the nozzle is regulated. It is desirable to calibrate the flow at different positions of the conical pin and check the flow during running, off and on. A scale with markings and a lever for adjusting the pin enable control of the flow from the platform of the sulphitation station.

(2) Nielsen plug cock—This cock is fitted to a small milk of lime tank in which constant level is maintained. The plug cock consists of a hollow plug with an opening through which lime flows out into the sulphiter. The inlet to the plug is through an aperture, the area of which can be adjusted by turning the plug. This side opening of the plug is in contact with the outlet of the milk of lime vessel. The operation of the plug can be mechanised and regulated from the platform of the sulphitation tank.

(3) Merry go round bucket feeding—This arrangement consists of a revolving horizontal wheel of merry go round type to which are attached buckets at equal spacings. The wheel revolutions can be varied by means of a variable speed pulley through which a motor provides the drive. The buckets move in a circular box with two compartments. In one compartment the buckets are filled by milk of lime coming from storage tanks while in the other the buckets are tilted by a special device and emptied. This compartment is connected to the sulphitation tank. Variations in rpm and size of bucket bring about variations in the dose of lime.

(4) In yet another design lime quantity is controlled by the flow of either the incoming or outgoing juice from the system.

(5) In one old design at Ugar14 the flow of milk of lime was regulated by the flow of juice. To the Duplex pump which delivered the mixed juice to the sulphitation unit was connected the device for delivering the lime to the sulphitation unit whereby the lime quantity would be proportional to the speed of pump and the juice quantity. This was later replaced by another device consisting of constant level lime tank with slotted partition and lever operated gate.
(6) In some designs the flow of milk of lime is determined by a float placed over the juice receiving tank. The juice flows through a weir and the float will rise or fall depending on the flow of juice. The lime tank is also provided with a V notch and receives lime continuously. Lever connected to the juice float tilts the tank thereby increasing or decreasing the V notch level.

All the above methods, with all their ingenious mechanisms fail to take into account the ultimate goal of maintenance of the desired pH of the treated juice, unless suitably connected to pH control mechanism.

(b) Electrical Method—Attempts have been made since last three decades to use proper pH indicator for the treated juice. Initial attempts were based on the measurement of pH electrometrically employing antimony electrode. The antimony electrode however failed to register correct pH due to coating of the same. Later on when in fifties the glass electrode which can withstand high temperature was developed it was possible to continuously measure pH in industrial practice. Mechanical devices of controlling lime could be operated more efficiently with the help of pH indicators. In sixties however pH controllers for juice clarification were developed wherein the milk of lime flow was controlled automatically in response to change in pH. The pH meter transmitted signals to an electrical system which started or stopped the flow of milk of lime.

7.3.4. Tank Design—In most of the designs two tanks are provided with a total capacity of 10-20 minutes hold up and fitted with stirring mechanism. One of these tanks receives the juice and lime and SO₂ continuously while the other one serves for correction and completion of reaction, sending out the treated juice continuously to a receiving tank. The stirrers running at about 50-100 r.p.m. are designed to aid circulation, in conjunction with the suitably placed baffles. There are some installations of sulphitation tanks without mechanical stirrers, wherein the circulation is expected to be brought about by the upward flow of SO₂ gas and the baffle plates, whereas in one design the recirculation of a part of treated juice into the sulphiter brings about forced circulation; however, this is likely to disturb the flocs once formed.

Circulation and mixing are aimed at bringing about turbulence and setting up currents without leaving any dead pockets of juice. It is in the centre of intense mixing that the reactants should be introduced and not in zones of smooth flow.

Yet another important factor in the design of the reaction tanks is the prevention of short circuiting of juice whereby the incoming juice finds shortest path to the outlet of the tank. This has been efficiently tackled by providing an inner cylindrical tank from which juice is withdrawn and which seals the outgoing treated juice from the incoming raw juice in some designs.

7.5. pH Controller work in Indian Industry—In view of the importance of pH control in clarification, attempts have been made since five decades to introduce automation in the dosing of chemicals employed. In juice defecation automation being restricted to lime dosing only was introduced very early but in sulphitation, automatic control of both the lime and SO₂ could not be established early though regulation of lime dose on the basis of
final pH of treated juice was introduced in Java and in a few factories in India notably Ravalgaon\(^5\) and Sakharwadi\(^6\). An ideal system of pH control shall incorporate following features—

(i) Since the results of clarification are dependent to a large extent on the amount of lime used, it is of utmost important that the requisite lime dose is fed to juice, all the time. In other words, the lime dose has to be given in the proportion which gives the desired results of clarification.

(ii) \(\text{SO}_2\) gas should be regulated for maintaining final pH of treated juice at 7.2 - 7.3.

(iii) It should be possible to regulate lime or \(\text{SO}_2\) so as to maintain the proper pH for either preliming or presulphitation. Regulation of \(\text{SO}_2\) valve at the sulphitation tank posed problems as it would lead to disturbing the working of sulphur burners which lacked combustion control arrangements. This led to control of lime valve, maintaining \(\text{SO}_2\) gas valve fully open in the initial stage of development of automation of sulphitation\(^17\). In recent years Central Electronics Engineering Research Institute of Pilani, have after considerable work and factory trials, established microprocessor based pH control system for regulating both lime dose and \(\text{SO}_2\) gas blown in the treatment tank.\(^18\) The salient features of this MAPCON system, operating successfully in a number of sulphitation plants in India are as under—\(^19\)

(i) The control system is useful at three points in the treatment tank for regulating preliming, liming in the tank and \(\text{SO}_2\) gas.

(ii) The sampled juice is cooled to 30°-40°C by heat exchangers before glass electrode is immersed in the same to prevent scale deposition on the electrode.

(iii) Glass calomel system of pH measurement is installed in which the reference electrode is kept in KC1 tank. At every sampling point glass reference electrode assembly is maintained.

(iv) The pH transmitter gives digital display of pH.

(v) Lime feed control valve is described earlier. A conical plug moves up and down the opening of a small pipe submerged in a small lime tank, for adjusting flow of lime to juice tank. The valve movement is controlled by independent stepper motor.

(vi) \(\text{SO}_2\) control valve is also designed on the same principle as above, in which rubber bellow is used to separate \(\text{SO}_2\) from the moving mechanism and the parts in contact with \(\text{SO}_2\) are fabricated of non-corrosive material. In short stepper motor driven valves have to be introduced for control of reactants.

(vii) Juice flow stabilisation system based on the installation of pneumatic control valve in the delivery line of the weighed raw juice maintains constant known supply of juice to sulphitation unit. This enables maintenance of lime dose in proportion to juice.

(viii) In the central console units are housed all the electronic units. The set points are fed to micro-computer which performs corrective action in the event of deviation of actual pH from set point. The stepper motor drive is controlled by this unit.
As regards control of S0₂ generation, this has been developed and introduced in some Indian factories with good results. This burner design includes (i) sensing of temperature of molten sulphur, sulphur vapour, S0₂ gas outlet and cooled S0₂ gas (ii) use of secondary air in combustion chamber, (Hi) temperature controller for sulphur burner.

(ix) automatic control of rate of sulphur burning to meet the requirement of sulphitation tank by regulating the air supply to burner.

The Mapcon system in conjunction with automatic operation of sulphur burning is reported to be satisfactorily operating in many factories and has improved the performance of sulphitation.

7.6. Sequence of application of different agents—In juice sulphitation, lime, S0₂ and heat are the main agents used in the treatment and different modes of their application have been tried or suggested. In general following methods are followed:

(i) Simultaneous liming and sulphitation of juice at about 70°C maintaining more or less neutral condition with respect of pH.

(ii) Preliming the raw juice at 70°C to 7.2 pH followed by simultaneous liming and sulphitation.

(iii) Shock liming to about 10 pH followed by neutralisation by S0₂. The juice which is preheated to about 70°C remains in high alkaline condition for only 8-10 seconds.

(iv) Presulphitation of juice heated to 65°-70°C, the pH being 5 or so. Alternatively presulphitation of cold juice to 3.8 - 4 pH followed by liming and sulphitation.

Needless to state the final pH of treated juice has to be 7.2 - 7.3 and the treated juice is heated to boiling point before being sent to settler, in any method of sulphitation that is followed.

There are different methods relating to sequencing of application of lime or S0₂, which have been tried and sometimes conflicting results have been reported on account of probably variations in the composition of cane juice. Nevertheless broadly the effects of variations in treatment can be summarised as under—

(i) Preheating of juice prior to treatment with lime and S0₂, to 65-70°C is essential for avoiding microbiological development and loss arising therefrom.

(ii) Presulphitation of juice leads to better settling characteristics of mud in the case of immature cane.

(iii) Preliming of juice heated to 80°C leads to improvement in settling in the case of juice containing high amount of polyphenols.

(iv) In some areas shock liming to pH 10.5 for 10 seconds followed by normal sulphitation has given good results in respect of colour of juice, settling and non sugar elimination.

(v) Simultaneous liming and sulphitation of juice has given good results in Deccan tract and this is by and large followed in this region.
In the light of the experience accumulated over the years it is evident that each factory has to decide its method of juice sulphitation which requires that—

(0) In the crushing campaign laboratory experiments have to be carried out to determine the composition of juice in different periods of the season.

(it) Experiments should be conducted on

(a) the optimum dose of lime

(b) method of sulphitation to be followed

(c) The initial preheating temperature of juice in the factory for attaining the desired results.

(Hi) P₂O₅ content in raw juice should be frequently estimated and minimum required dose for good clarification decided by trials.

(ID) The design of the sulphitation equipment should permit any of the variations in the mode of application of lime and S0₂ i.e. preliming, shock liming, or presulphitation.

(v) Automation of lime dosing and S0₂ on the basis of desired pH at different points will be of great help in controlling the process conditions.

view of the various designs prevailing in the industry, each with its own special characteristics it is felt that a number of variants could be developed taking into account the juice characteristics and local requirements of factories. However, there are certain basic factors which need to be taken care of while designing a system of juice sulphitation in any modern plant These are as under—

(1) Thorough mixing of reactants with the juice is to be ensured by installing efficient stirring mechanism and baffles.

(2) Sealing the zone of treated juice from the incoming raw untreated juice as well as the reactants is necessary to obtain uniform treatment of the juice.

(3) Sample of juice for pH control should be drawn from this zone (treated juice) allowing a minimum time lag.

(4) The treated juice leaving the sulphitation tanks contains flocs of precipitates which should not be disturbed when it is pumped to the clarifier through the heaters. A 'screw' pump would be preferred from this angle.¹⁹

(5) The system should possess in-built flexibility of operation with respect to the sequence of liming and sulphitation (preliming or presulphitation etc.) since during different periods of the season the juices may respond to different treatments.

(6) The system should take care of capacity increases as well as increase in lime dose up to at least 25%. In fact it may even be necessary to enhance the sulphur and lime consumption by 50% over the normal and the equipment design should take this into account.

The adoption of pH controlled flow of milk of lime and S0₂ is strongly recommended in
conjunction with glass colomel pH indicator and controller. In this connection following further precautions are essential.

(1) pH of sulphited juice at 70°C i.e. the temperature of the reaction is lower by 0.3 or so than the pH of cooled juice. Hence temperature compensation is required\textsuperscript{16A}.

(2) The glass electrode is extremely fragile and sensitive. Besides cleaning and calibration, check with a laboratory model pH meter is required.

(3) No lime deposition in the lime feeding mechanism is to be tolerated.

8. EFFECTS OF SULPHITATION

8.1. The principal aims in clarification are—

(1) To remove suspended impurities in juice.

(2) To bring down colour contents.

(3) To obtain juice free from turbidity.

(4) To achieve rise in purity by reducing the overall nonsugar content in juice.

The major agents employed in achieving the above objective in sulphitation are—

(a) Heat

(b) Lime

(c) Sulphur Dioxide and

(d) Soluble phosphate or phosphoric acid.

8.2. Phosphates—In North India juices contain around 300 p.p.m. \( P_2O_5 \) per litre while in Maharashtra region juices contain a round 80-150 p.p.m. \( P_2O_5 \). As a result no phosphates are added to juices during clarification in North while in Deccan addition of about 100-150 p.p.m. of \( P_2O_5 \) in the form of either triple superphosphate or phosphoric acid is essential for obtaining good clarity of juice. Each factory has to estimate the phosphate deficiency of its juices from time to time and decide upon the norms of phosphate dosing with the ultimate object of getting proper clarification. Phosphoric acid has been recently introduced with better results in respect of clarity of clear juice, scale etc. as compared to triple superphosphate. The phosphate content of clear juice is reported to be around 60-80 p.p.m. irrespective of the phosphate doses given.\textsuperscript{20} Phosphate is added to weighed raw juice before the same is sent for heating. Phosphate addition must be proportional to the quantity of juice and proper proportioning arrangement is essential for optimum utilisation of the same in preference to ad-hoc addition or continuous flow of phosphate extract into weighed juice receiving tank. All the phosphate present in raw juice does not react with lime to form insoluble tricalcium phosphate since a certain portion thereof which might be in colloidal state remains unreacted. However, the externally added phosphate aids clarification by formation of tricalcium phosphate on which impurities get adsorbed.
8.3. CaO—CaO content in clear juice is a function of (i) initial CaO content of raw juice, (ii) organic acids present in the original juice and (iii) acids formed in the clarification process. Initial CaO content in cane juices of Deccan Tract varies from 600 to 1000 mgms/litre much higher than in north Indian factories which increases by 10-25% during clarification. The increase in CaO is attributed to the neutralisation of acids present in the juice with the formation of organic acid salts of calcium which are not removed during clarification. Apart from the acids originally present in the juice, some acids are generated as a result of

(a) decomposition of reducing sugars and

(b) formation of minute quantities of sulphuric acids during S0₂ generation; these inevitably lead to enhanced calcium salts in clear juice.

8.4. Colouring compounds—Out of the naturally occurring colouring substances in cane juice polyphenols increase the colour content in process and impart dark colouration to the clarified juice, besides affecting the settling properties of the treated juices. In sulphitation the polyphenols are removed upto 45% by adsorption on the calcium sulphite precipitate and cannot be eliminated completely. The dark tinge in white sugar produced from juice rich in polyphenols is ascribed to the formation of phenolic iron compounds.

Other colourants of importance which are formed during processing are caramel and melanoidins generated unlike the polyphenols which are of natural occurrence.

Melanoidins—Melanoidins are formed as a result of reaction between reducing sugars on the one hand and amino acids as well as amides in solution. This reaction known as Maillard's reaction imparts reddish brown colour to the juice. The first stage of this reaction is reported to be formation of n-glucosides. Preliming of juice has been found to reduce the amino acid content of clear juice with consequent reduction of melanoidin formation, and would thus help in reducing the colour content arising therefrom.

Caramel—Caramels are formed due to the action of heat on sucrose and heat and alkali on reducing sugars, imparting yellow or brown colour to the juice. In the mechanism of caramel formation Lobry De Bryun and Alberta Van Ekenstein reaction transforms the reducing sugars into an equilibrium mixture of glucose, fructose, mannose and saccharanic acids in the first stage with the ultimate formation of caramel. Caramel enters the crystal lattice of sucrose and imparts yellow tinge to it. It is therefore desirable to avoid conditions conductive to caramel formation by keeping the hot juice in contact with lime for the shortest possible time or by avoiding alkaline conditions altogether.

8.6. Sugars—Out of the sugars the sucrose is unaffected in sulphitation process while reducing sugars might undergo decomposition in the absence of proper control on pH or due to high contact with heat in the clarifier to a small extent. During prolonged stoppages the loss of reducing sugars is discernible. But during normal running with rigid control on process parameters the reducing sugar destruction can be controlled to negligible level.

8.7. Ash percentage is more or less unaffected and in many cases the ash content increases during sulphitation.
8.8. Purity change—The change in purity during sulphitation of raw juice varies widely from -0.3 to +0.4 depending on the cane juice characteristics as also the control on parameters of operation.

9. COMPARISON OF DEFECATION WITH SULPHITATION

Lime defecation of cane juice has been practised in Indian Sugar industry only since last two decades and has been confined only to the process of raw sugar manufacture. Work done in Deccan sugar industry has shown that defecation—

(a) gives higher rise in purity by one unit or so
(b) gives better settling of treated juice and
(c) results in less scale formation as compared to sulphitation.24

The CaO content rise in defecation has been found to be less than in sulphitation by 200-300 mgms/litre. In regard to sulphitation the rise in calcium content on account of neutralisation of organic acids in the juice has been found to be about 200 mgms/litre the further increase in CaO content being due to calcium sulphite and calcium sulphate compounds as well as the calcium salts of organic acids formed by decomposition of reducing sugars. Possibilities of calcium sulphite being converted into sulphate during sulphitation process, by oxidation have been indicated.25 Similarly some S0\textsubscript{3} generation in the sulphur burning cannot be ruled out. As is well known the solubility of calcium sulphate in sugar solution is 150 times that of calciumsulphite and SO\textsubscript{2} production has to be controlled from this angle. According to Perk even in Java the same trend in respect of CaO and purity rise had been observed with defecation and sulphitation before Second World War.26

However, in respect of two important parameters the sulphitation scores over defecation; one is the resultant colour content of clarified juice and the other is the colloid removal in clarification. Sulphitation reduces colour value measured at 560 nm of juice by 29% while with defecation the reduction is only 1.35%. Moreover during evaporation, the clear juice from defecation on concentration was found to exhibit increase in colour content by nearly 10% while the juice clarified by sulphitation recorded increase of 1.8% only.27 This clearly shows the beneficial role of sulphite in checking colour formation during heating, and evaporation.

As regards scale formation in evaporator higher inorganic salts of calcium viz. sulphite and sulphate in juice clarified by sulphitation than in defecation clarified juice are primarily responsible for the greater incrustation in evaporator when practising sulphitation.

10. NEW TECHNIQUE OF JUICE CLARIFICATION

This Process is described in Part-IV.
11. ADDITIONAL CHEMICALS USED

In addition to lime and sulphur dioxide used in clarification by sulphitation there are a number of chemicals which have found wide application under specific conditions while there are some, the use of which is being advocated after extensive trials. Some of the important ones are discussed below—

11.1. Phosphoric acid—As already explained replenishment of phosphate in the juice by addition of triple superphosphate or phosphoric acid is a regular practice in some parts of India like Maharashtra, where the juices are deficient in phosphate. Triple superphosphate contains around 43-45% $P_2O_5$ while commercial phosphoric acid contains about 54% $P_2O_5$.

In sugar mills hot water extract of triple superphosphate is prepared in special tanks of acid resisting material. This extract is found to contain 26 mgms of CaO per 100 mgms of $P_2O_5$ plus some sulphate also. As against this the phosphoric acid which is in liquid state introduces only minute quantities of iron and other impurities.

As regards single superphosphate, which contains 15-18% $P_2O_5$ more impurities in the form of CaO, $S_0_4$ and acids are introduced for the same amount of $P_2O_5$ from single superphosphate as compared to triple superphosphate. Its use is therefore not recommended.

Phosphoric acid, on account of its extremely low impurities as compared to the triple superphosphate extract is recommended for use in clarification.

Phosphoric acid free from objectionable impurities is manufactured from rock phosphate by employing process involving use of electric furnace with carbon electrodes. Commercial phosphoric acid is a clear liquid packed in polythene or PVC jars and contains about 55% $H_3P0_4$. It has to be sufficiently diluted with condensate before being used.

11.1.2 Bentonite—This clay which is an aluminium magnesium silicate is colloidal in nature and presents large surface for adsorption as shown by the fact that one cubic inch (16.39 cm$^3$) of the dry clay when mixed with water may produce a surface of one acre. When used as an adjunct to sulphitation it is reported to give better settling of muds and result in higher elimination of colloids. Sodium bentonite suspension in water prepared by adding soda to bentonite slurry, when added to sulphited juice at the rate of 250 mgms per tonne of cane is reported to have given good results in Argentina while processing refractory juices.

Although some work on the use of sodium bentonite in sulphitation has been carried out in India, its adoption on commercial scale has not met with success probably because it has not become economically attractive. Nevertheless more investigational work needs to be undertaken for carrying out techno-economic evaluation of the use of this clay under different operating conditions.

11.2. Settling aids—In many sulphitation factories settling of treated juice in clarifiers present difficulties particularly during peak maturity period, affecting the rate of cane grinding and also quality of sugar. An important development in the last two decades in meeting this difficult situation has been the use of minute quantities of synthetic polyelectrolytes,
as flocculation aids. These chemicals are synthetic polyacrylamides, partially hydrolysed, with very high molecular weights (7 to 10 millions), which on dissolving in water give highly viscous solution and are added as very dilute solutions. The efficacy of these polymers depends on the molecular weight and degree of hydrolysis. They are mostly anionic in nature. A dilute solution of the settling aid is fed continuously to the treated juice on its way to the settler after the juice has been boiled. It is desirable to feed the solution near the point of entry into the subsider in two or three streams to ensure proper and even dosing, the dose varying from 2 to 6 p.p.m. According to one theory the large chain molecule of polyacrylamide serves as a bridge between different particles of precipitate with resultant formation of large aggregates which settle rapidly. The treated juice after addition of flocculant should not be subjected to vigorous stirring in order that the flocs once formed are not disturbed. Thus after treatment with polyacrylamide pumping of juice is to be avoided. Common flocculants which are available in Indian market for use in sugar mills are Separan AP 30, Sedipur TF2, Magnofloc 26 & 27 Trufloc etc. Every factory should carry out its own settling tests with samples of different flocculants with a view to study the efficacy of the same and then decide on using the one that is most suitable under conditions obtaining there.

11.3. Magnesia—Magnesium oxide MgO in combination with lime has been commercially used in Hawaii, Puerto Rico, Jamaica etc. in cane juice defecation with the main object of reducing scale formation in evaporator but the clear juice shows foggy appearance and is turbid as compared to lime clarified juice.\(^{32}\) Work in India on the use of Magnesia in sulphitation factories in partial replacement of lime has not given any promising results.\(^{33}\)

11.3. Formaldehyde—Schmidt\(^{34}\) has stated that formaldehyde when added to cold raw juice at the rate of 0.5 to 1.0 p.p.m. before defecation improved the sedimentation characteristics of treated juice. Particularly with refractory juices from drought affected cane the formaldehyde is reported to give better thickening of muds. However its use in sulphitation has not been reported.
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CANE JUICE CLARIFICATION
A—SULPHITATION

Mixed Juice → Juice Heater → Sulphitation Tank

Clear Juice ← Clarifier ← Juice Heater

Settled Mud

Filtrates ← Filter → Mud Thrown Out

Mixed Juice → Heated to 65–76°C → Sulphitation Tank

Phosphate Solution

Mud to Filter ← Clarifier ← Heated to 100–103°C

Mud Thrown Out

Clear Juice
1. Raw Juice Carbonation

(A) Mixed juice → Juice heater → 1st carbonation Tank ↓

Juice heater ← 2nd carbonation ← Filtrate Filter

↓ Filtrate → Sulphitation tank → Neutral clear juice

(B) Mixed juice → heated to 55°C → 1st carbonation tank ↓

↑ 2nd carbonation tank ← Filtrate to heater Filter

↑ Carbon dioxide
↑ Lime
↑ Carbon dioxide

Filter → Sulphitation tank → Clear juice → Evaporator-syrup

(C) Middle Juice Carbonation

Mixed juice → Juice heater → Juice limed → Evaporator ↑

↑ Lime

↑ Filtrate

↑ 2nd carbonation ← Filter ← Ist carbonation tank ← Juice of 40° Bx from 3rd body

↑ Lime
↑ CO₂

↓ Juice heater → Filter ← Filtrate Sulphitation tank → Evaporator 4th body ↓

↓ Syrup
PART-IV

JUICE CLARIFICATION

Carbonation: Process

1. DEVELOPMENT

Carbonation, implies formation of carbonate of lime for purification of juice and was introduced in cane sugar manufacture for the first time in Java in 1876. The technology of carbonation was similar to that being practised in beet sugar-industry and involved addition of excess lime to hot juice followed by C0₂ in two stages. The first saturated juice was filtered and the filtrate saturated to the point of obtaining minimum CaO content in the juice. In the early stage 4-5% lime stone was used on cane, which increased the cost of the production of white sugar. Studies on the various reactions taking place in carbonation and their influence on the sugar recovery aspects, conducted in the subsequent decades threw more light on the chemistry of the carbonation process and led to establishing optimum conditions with regard to temperature, pH, time of reaction and lime doses. Significant landmark in the development of carbonation was the process, based on the optimum conditions of first and second carbonation as formulated by De Haan in the second decade of the twentieth century. Since then number of modifications were introduced in the process such as—

(i) middle juice carbonation,

(ii) use of phosphates, besides control systems and continuous operations. Carbonation is employed only for white sugar manufacture from cane in some developing countries and is gradually being replaced in India in favour of sulphitation.

2. PRINCIPLES

Calcium hydroxide combines with carbon dioxide to form calcium carbonate

\[ Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O. \]

In a saturated Ca(CO₃) solution the solubility product will be—

\[ C = \frac{(Ca^{++})(CO_{3}^{-})}{CaCO_3} \]

Thus for lower concentration of Ca⁺⁺ in solution the concentration of CO₃⁻⁻ has to be high.

When carbonate reaction is brought about as above in juice, complex compounds of lime, CaCO₃ with juice components are produced. According to Van Ginneken and Aten¹, when lime and CO₂ are made to react in sucrose solution, the precipitate formed is a complex compound of sucrocarbonate of lime represented by the formula—

\[ [Ca(OH)_2]_m [CaCO_3]_n [C_{12} H_{22} O_{11}]_z \]
These unstable compounds are formed at high pH > 11 which are decomposed at lower pH.

The temperature of first carbonation should be 55°C and not higher in view of the rapid decomposition of reducing sugars at higher temperature and high pH. The saturation and filtration of carbonated juice takes place in two stages for completion of precipitation of lime and removal of non-sugars. The second carbonation is preceded by heating of filtered juice from first carbonation to 70°C to check growth of microorganism particularly the lactic acid bacteria. In the second carbonation the lowest CaO is aimed at and to facilitate precipitate formation and good filtration for removal of nonsugars a certain minimum amount of CaO i.e. 300-800 mgm. per litre has to be maintained in filtered juice of first carbonation. In the first carbonation optimum pH is 10-10.5 while the second carbonation juice pH comes down to 8-8.5. The residual alkalinity is brought down to neutral state i.e. 7-7.2 pH by applying sulphitation.

3. PROCESS:

(a) First carbonation: The raw juice is heated to 55°C and to the hot juice milk of lime of 15°Be' is added to 10.5 pH. The limed juice is retained in this condition at least for four minutes to ensure floc formation, dehydration of gums and pectins and formation of calcium pectinate. This step is followed by carbonation in which the dose of lime and saturation are so adjusted as the maintain level of alkalinity at 500 to 1000 mgm of CaO on phenolphthalein using Dupont paper for control. On completion of lime dose the final juice will have alkalinity of 400-800 mgms. CaO. Total lime consumption is 1-1.5% on cane, or in terms of limestone 2.5-3% on cane. This treated juice along with the precipitate is filtered either in filter presses or continuous filters and filtrates sent for second carbonation.

(b) Second carbonation stage involves saturation of the filtrates which have pH of 10-10.5, to precipitate free CaO and bring down level of titratable CaO as completely as possible. In second carbonation 200-400 mgm. CaO per litre of juice are precipitated and the final pH is about 8.8-8.5. The second carbonation is preceded by heating the filtrates from first filtration to 70°C. This preheating avoids development of lactic acid forming bacteria and helps formation of CaCO₃ precipitate. After reaching the desired state of saturation and precipitate formation, the juice is filtered again and the filtrates sent for neutralisation in sulphitation tank where the pH of juice is brought down to 7-7.2.

4. MIDDLE JUICE CARBONATION

This process developed in Java before second world-war and practised extensively in Taiwan marks significant departure from the established double carbonation of juice in as much as the carbonation process is applied to partially concentrated defecated juice. The steps involved are—
(i) Raw juice pre-heated to 100-102°C is limed to pH 7-7.2 and allowed to remain in this state before being sent to evaporator; without settling or filtration.

(ii) In the multiple effect evaporator it is withdrawn from the vessel in which the brix attained is 40°.

(iii) The middle juice of 40° Bx is treated with lime and CO\textsubscript{2} in carbonation tanks to pH 9.8-10.3 and filtered in filter presses.

(iv) The filtrate from first carbonation juice is treated with CO\textsubscript{2} to pH 8.2 - 8.5 and heated to 75°-80°C before second filtration.

(v) The filtrate from (iv) is sulphited to 7.0-7.2 pH and sent to the last body or penultimate body of the evaporator for concentration to 60°Bx.

The advantages of this process are—

(i) reduction in lime consumption by 30-40%,

(ii) elimination of sulphates with consequent reduction in scale formation in the evaporator,

(Hi) higher non-sugar removal as compared to raw-juice carbonation\textsuperscript{2}.

5. CARBONATION PHOSPHATATION\textsuperscript{3}

This process was developed in Taiwan to improve the keeping quality of white sugar and arrest the development of colour during storage. Besides, the problem caused by S\textsubscript{0}\textsubscript{2} content of final sugar which comes in the way of its use in the food industry, is solved. In this process upto second carbonation of the juice the technique followed is similar to conventional double carbonation. To the filtered second carbonation juice is added phosphoric acid to pH 6.8-7.0 and without filtration the neutralised juice is concentrated in evaporator to syrup of 60-65° Bx. This syrup is heated to 85°C and filtered after addition of a flocculant and filter aid. In the test procedure in which sugar from conventional and from phosphatation process was kept at 75°C for 96 hours - treatment equivalent to year's storage-the colour development in the phosphatation treated sugar was found to be considerably less than in the sugar from carbonation-sulphitation process. Addition of phosphoric acid followed by filtration of syrup increases the cost of manufacture but offers distinct advantages in respect of keeping quality of white sugar.

6. EFFECTS OF CARBONATION ON JUICE COMPOSITION

Removal of non sugars in carbonation purification is much greater than in either defecation or sulphitation process with the result that purity rise of 4 to 5 units is obtained by double carbonation as against 0 to 1 unit by the latter processes. Investigations in Java and Taiwan have shown that\textsuperscript{4}:

(i) Ash content in raw-juice is brought down by 35-40% in double carbonation. The SiO\textsubscript{2} is removed upto 95%, while CaO, MgO and Fe\textsubscript{2}O\textsubscript{3} are reduced by 70-80%.
(ii) Sulphate removal in middle juice carbonation is about 60-70% much higher than in juice carbonation.

(iii) Organic nonsugars like gums, pectins and nitrogen compounds are eliminated to a large extent in the filtration of first carbonation.

(iv) Reducing sugars in raw juice are destroyed to the extent of 25-33%.

(v) 30-40% nonsugars originally present in mixed juice are removed in both double carbonation processes as applied to raw juice and middle juice.

In some Indian carbonation factories the purity rise of 2-4 units with 20-30% reducing sugar destruction is reported.

7. EQUIPMENT

7.1. a. Lime kiln is an essential item in the entire equipment set up of carbonation factory in as much as CO₂ required for process is drawn from the kiln adjacent to the factory. The details of the kiln are given elsewhere. One Kilogram of limestone for dissociation requires 700 K.Cal. of energy, which is furnished by burning coke. Layers of coke and limestone are laid alternately for uniform supply of heat. The coke with calorific value of 7,000 K cal/kg. is consumed in the proportion of 7 to 10 kg. per 100 kg. of limestone.

The lime Kiln operating continuously is charged at the top and CO₂ withdrawn from top while lime is obtained from the bottom. The gas at 70°-120°C is passed through a washer and contains about 30% CO₂ The gas from washer at 60°C has pressure of about 5 to 12 cms. of mercury when connected to suction of CO₂ pump which delivers it at pressure of 0.4 to 0.5 kg/cm². The capacity of limekiln required is calculated at the rate of 480 kg/m³/24 hrs for CaO while the CO₂ to be supplied is 60m³/tc.

7.2. Carbonation tanks: (1) Batch carbonation; First carbonation vessels are vertical cylindrical tanks of 4-6 meter height holding juice column of 2-3 m. the. remaining space being provided for frothing. Second carbonation tanks are identical in construction but with less height than those for first carbonation.Besides the juice inlet, overflow and outlet connection,, the tank is provided with steam coil at the bottom and CO₂ distributor which is a star shaped device with serrated edge. For breaking foam perforated pipes for steam blowing above the top of juice level, is helpful. According to Honig for batch system the volume of first carbonation tank should be around 2m³/tch. and about 0.2m³/tch. for second carbonation as the optimum requirements.

7.3. Continuous carbonation—Continuous operation is common with second stage of carbonation. Automation of operation with pH controller has also been introduced. In Taiwan the continuous first carbonation system developed consists of four saturation towers out of which the first three had two liming points, one at the juice entry and the other in the middle of the tank, while the fourth tank has lime connection only at the juice inlet point. CO₂ is controlled automatically by pH controller. The results obtained were more or less the same as obtaining with batch operation. However the experience with continuous carbonation at Champaran Sugar Co., Barachakia was not encouraging as the
results obtained showed inferior performance compared to batch operation despite the automatic control of pH.\textsuperscript{7}

7.4. Filters and settlers—Since the establishment of double carbonation process plate and frame type filter presses were employed for many decades until new types of continuous filters were introduced. The filter press operation is labour intensive on account of number of units involved and batch operation of the system. The merit of filter press operation lies in the thoroughness of filtration through cloth which results in clear juice when the conditions in carbonation tanks are normal. Major disadvantage with filter press operation is besides being labour intensive it gives high sugar loss in cake and requires frequent change of cloth. Rotary vacuum belt filter with nylon cloth cover, on account of its continuous operation has replaced the conventional filter presses in many carbonation plants in recent years. Dorr Oliver Co. supply a thickner for first carbonation juice which can operate in conjunction with the continuous rotary vacuum filter. This system operation would result in (i) decantation of clear juice accompanied by thickening of mud (ii) reduced load on filtration equipment (iii) continuous operation.

Experience with working of Dorr thickener and Dorr Oliver vacuum filter at Mawana Sugar Works in 1970\textsuperscript{8} showed reduction of wash water by 30-35\% and pol loss in filter cake less by 60-70\% with this system, compared to conventional filtration with filter presses. The retention of juice in the thickner was 1 hr. and the system appeared to suit the conditions of continuous operation.

Continuous filtration of second carbonation juice is more common than the first carbonation juice. 'Ganga Sugar Corporation Ramkola, after installing G.P. filters for second carbonation juice have reported satisfactory working results.\textsuperscript{9} This filter separates clear juice from thick mud, in the filter elements covered with cloth when fed with second carbonation juice at constant low-head. As the filtration rate falls, the slurry which is concentrated mud is drained out, the filter bags cleaned and cycle restarted. This slurry can either be further filtered in plate and frame type presses or mixed with first carbonation juice. Advantages claimed are—

(i) reduction in manpower,
(ii) lower sugar loss in cake,
(iii) automatic operation.

8. CARBONATION IN INDIAN INDUSTRY

8.1. In the carbonation plants of India, located mostly in the northern belt of the country lot of changes have been made in the last two decades in the technique and equipment with a view to bringing down the cost of production. These include the following—

(i) Continuous first carbonation and continuous second carbonation
(ii) Continuous filtration of second carbonation juice
(iii) Continuous filtration of first carbonation juice
(iv) Middle juice carbonation

(v) Phosphatation of second carbonation juice:

At Kichha sugar factory carbonation plant, phosphatation of second carbonation juice without filtration followed by settling in a subsider and sending the settled mud to raw-juice has been adopted which is reported to have given good results in respect of sugar-colour. Syrup sulphitation however could not be eliminated along with sulphitation of second carbonation filtrates. Sugar quality improvement together with lower process loss are claimed to be main advantages of this process.

8.2. Status of carbonation in India—Out of the total plantation white sugar manufactured in India only 10-15% is accounted for by carbonation process. This proportion is gradually dwindling on account of the trend towards replacement of carbonation by double sulphitation witnessed in the past decade and no new sugar plants are being set up employing carbonation. This is attributed to the problems of very high consumption of lime—nearly ten times that in sulphitation. The sugar from double carbonation and double sulphitation process has been found to deteriorate in respect of colour on storage and substitution of phosphoric acid for sulphur dioxide is expected to improve the situation to some extent, but the overall costs involved may not be economically justified in the context of Indian conditions. Furthermore the quality of sugar produced by double sulphitation has considerably improved in the last four decades in Deccan and some north Indian areas and the sulphitation plant sugar is comparable to that from carbonation process with better keeping quality. Against this backdrop the future of carbonation appears bleak in Indian industry.

9. CAPACITIES

The carbonation process involves elaborate treatment of juice and thus requires more equipment as compared to sulphitation. The capacities to be provided at various points are as under—

(i) Lime kiln: for continuous lime kiln according to Tromp the volume of lime kiln should be calculated on the basis of production of 500 Kg. of lime per m³ per 24 hours.

(n) C0₂: Hugot after assuming 25% CO₂ in the kiln gas and providing for safety margin of 10% considers the optimum capacity of CO₂ pump to be 6,616 m³/hr for a crushing rate of 100 t per hr. when lime consumption is 1.8% cane.

(Hi) The carbonation if operated as batch system will require four tanks for first carbonation and four for second carbonation. Each tank for first carbonation will have a cycle of operation of half an hour including time for filling, discharging and reaction while the second carbonation will complete one cycle of operation within 15 minutes. Honig recommends volume of 1.4—1.7 m³/tch for first carbonation and 0.11 - 0.15 m³ for second carbonation tanks for batch operation.
(iv) Filtration: When using plate and frame type filter presses the filtering surfaces specified by Tromp are

(a) first carbonation: 6-8 m²/tch

(b) second carbonation: 4-5 m²/tch.

10. PRECAUTIONS

Carbonation is a robust process of clarification which yields positive nonsugar reduction and thereby higher recoverable sugar from juice than sulphitation or defecation methods provided all the conditions of the process are observed with respect to—

(i) pH and CaO content

(ii) temperature

(iii) time of reaction.

Apart from the proper dosing of lime it is essential to observe following precautions—

(i) Sanitary conditions at the filter station assume special significance and filtration after second carbonation has to be at 70°C to prevent microbial growth particularly the lactic acid forming bacteria which thrive at the expense of sugar.

(ii) Longer contact of alkali, than required for the reactions results in greater destruction of reducing sugars.

(iii) Washing of filter cake at the end of filtration cycle needs to be thorough to reduce loss of sugar in filtercake.
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PART V
OTHER CLARIFICATION PROCESSES

LION-EXCHANGE

Soon in the wake of discovery of synthetic resins with ion exchange property by Adam
and Holmes in 1935, work on application of ion exchange resins to sugar industry, for
deionisation of juice was commenced and it was found that deionisation and
decolorisation of sugar juices could be achieved by ion exchange treatment. The post war
period saw rapid advance in the field of ion exchange applications in industry and
presently these resins are being widely used in beet sugar industry and sugar refineries.
In cane sugar manufacture ion exchange process has the potential of production of direct
consumption white sugar with minimum sugar losses in process and considerable
amount of research work has been carried out in India and different sugar producing
regions like Hawaii, but so far the progress is held up at the pilot plant stage only.

2. RESINS

2.1. Resins—These are large organic molecules, insoluble in most liquids including water,
which possess active basic and acidic groups. These organic polymers have ionic sites
dispersed throughout, at which ions are bound. The skeletal network of the resins is
porous and through the interstices the ion can move freely. The ions are bound
electrostatically to ionic sites and they can be displaced by other ions of similar charge.
The cation exchange resins for instance possess negatively charged groups like carboxyl
(-COOH) or sulphonic acid (-SO₃H) which bind positive ions. Thus with these resins
only positive ions are exchanged while the anions pass through without getting bound.
Anion exchange resin is insoluble matrix which has positive charged ionic sites at which
negatively charged ions or anions are bound and can be exchanged with other negatively
charged ions. The active groups of anion exchange resins are basic amino (-NH₃) and the
strength of these groups determines the degree of exchange with acid groups of the
solutions which come in contact with them.

2.3. Mechanism—A cation exchange resin can be represented as R´ M⁺ wherein R is the exchange
site in the resin matrix while M is the cation bound in the resin. Likewise the anion
exchange resin is in the form of R´X with R´ as exchange site and X" as the negative ion
bound to the positive exchange site. Considering a simple case of deionisation of water
containing sodium chloride, when the solution is passed through cation exchange resin in
the hydrogen form the Na⁺ ions will replace H ions according to following equation R-H⁺
+ NaCl→ RNa⁺ + H⁺ Cl⁻ Thus the resulting solution will be acid HCL which
when passed over anion exchange resins in hydroxide form R⁺ OH⁻ the chloride ion Cl⁻
will be bound in the resin with release of OH⁻ ions. R+ OH⁻ + H⁺ Ch⁻→ R⁺ Ch+ H⁺ +
OH⁻. The net effect is Na⁺ and Cl⁻ ions getting fixed up in the cationic and anionic resins
and the H⁺ and OH⁻ ions combine to form water. The resins have limited capacity for
exchange of ions and when all the exchange sites of cation resins are occupied by Na⁺
ions the resin can no longer absorb Na\(^+\) ions when the resin is considered to be exhausted. In the same manner the anion exchange resin bed is not capable of removing Cl\(^-\) ions after it is exhausted and both the resins can be regenerated by treating with acid and base, the cation and anion exchange resins respectively. In the case of softening of hard water, the water is passed over cation exchange resins, R-Na\(^+\) the exchange sites of which are occupied by Na\(^+\) ions and Ca\(^+\) ions in water replace the Na\(^+\) ions.

\[
2RNa^+ + Ca^{2+} \rightarrow (R')2Ca^{2+} + 2Na^+
\]

Cations are now bound in the resin matrix, releasing the Na\(^+\) ions in the effluent. After the resin is exhausted, a solution of NaCl is passed through it for returning it to original form and reviving its ion exchange property. Selection of resin for a particular application is decided by the composition of resin as also its property and a number of different types of resins have been prepared to suit various needs of process industries.

2.3. Operation—Ion exchange resins are in the form of spherical beads packed in vertical columns, supported by perforated or porous sheet in cylindrical vessels. The liquid to be deionised is fed at the top and flows through the column. This way the liquid gets progressively deionised as it meets new layers of unreacted resin in the course of downward flow. Soon the stage of saturation is reached when the ions cannot be accommodated in the resin matrix and the liquid passes down the resin unreacted. This stage of resin getting exhausted is termed as 'break through', the resin bed is said to 'leak' or pass the liquid without ion removal. The complete cycle of operation in deionisation from 'start' to 'restart' consists of following stages—

(a) Liquid to be deionised is passed through the resin columns until the resin is exhausted and liquid flow discontinued.

(b) The liquid remaining in the column is displaced. This step is known as sweetening off, while treating sugar solution.

(c) The above step is followed by backwash in which water flows upwards in the resin bed. This serves two-fold purpose viz. undesirable impurities are eliminated from top and the resins are classified.

(d) the backwash is succeeded by passing regenerating solution from top for regenerating the resins.

(e) Excess of regenerant is removed by running water.

(f) Start of second cycle. Life of resin is limited to 200 to 800 cycles depending on the composition of resin and nature of application.

Instead of two separate treatments with cation and anion exchange resins, a mixed bed of these resins can be used and the operation will be identical to the separate treatment up to the point of regeneration. Regeneration of resins is preceded by separation of cation resins from the anion resins which have to be regenerated separately.
3. APPLICATION TO SUGAR MANUFACTURE

3.1. Application to sugar manufacture—Ion exchange treatment has found wide application in beet sugar industry and in sugar refineries but its use in cane sugar manufacture has not been established for economic reasons despite of considerable amount of research work conducted in the past four decades on deionisation of cane juice for production of direct white sugar. The major cost elements in ion exchange treatment are—

(i) cost of resins which have to be replaced after 400-500 cycles,
(ii) cost of regenerants.

Perhaps after these are further brought down deionisation of cane juice in plantation white sugar process might become economic. In modern raw-sugar refineries decolorisation of sugar liquors by carbon treatment is followed by polishing by ion exchange treatment, employing decolourising resins. In beet sugar industry these resins are used for decalcification and decolorisation.

3.2. Selection of resins—The ion exchange resins remove the electrically charged inorganic or organic constituents in aqueous solutions by the process of exchange of their ions. There are in all four types of resins viz. strong and weak anion, strong and weak cation exchanger resins. The deionisation of raw cane juice being impracticable on account of suspended and organic impurities like gums, pectins etc. which clog the resin bed, preclarification by defecation or any other process is found essential. The resins employed are strong cation exchange resins and weak anion exchange resins. The ion exchange treatment can be practised by—

(i) direct bed system,
(ii) reverse bed system,
(iii) mixed bed.

In direct bed system the juice is first passed through strong cation exchange resin bed and the resulting acidic juice is freed of its acidity by passing through anion exchange column. The preclarified juice has to be cooled to 15° - 20°C to minimise sucrose inversion in cation exchange treatment. In the reverse bed system the juice is passed through first anion exchange resin followed by cation exchange treatment for removal of alkalinity while the treatment in the mixed bed consisting of both cation and anion exchange resins involves no ill effects of acidic or alkaline conditions on sugars. The essential physical characteristics of good resins are—

(i) minimum solubility,
(ii) resistance to attrition on account of mechanical or chemical causes,
(iii) high exchange capacity with the ions in solution
(iv) good regeneration efficiency requiring minimum quantity of regenerents.
(v) maximum number of cycles of operation before the resin bed needs to be replaced by fresh charge of new resins.
4. WORK IN INDIA

Considerable amount of work was carried out at the National Sugar Institute, Kanpur by S. Mukherjee and others, on application of ion exchange technique for refining of juices preclarified by different processes like sulphitation, carbonation etc. Pilot plant trials on demineralisation of juices clarified by sulphitation of raw-juice conducted at this Institute encompassed studies on the entire process of sugar manufacture including crystallisation upto final molasses stage. The results reported are as under—

(i) Mixed bed of strong cation and weak anion exchange resins gave better performance in respect of deionisation and sucrose inversion than the direct bed treatment. The juice dilution was about 3-5%.

(ii) Deionisation to the extent of 95% ash removal was obtained.

(iii) Ammonia was found more suitable as regenerant for anion exchangers than soda ash as 85-90% of it could be recovered by distillation & its effluent was easy for disposal.

(iv) Increase in sugar recovery by 10-11% was obtained over the conventional processes.

(v) The final molasses containing over 60% sugars, could be considered edible with its 3-4% ash.

(vi) Scaling in evaporator was insignificant.

(vii) Sugar produced was superior in quality to the normal white sugar produced by double sulphitation process.

(viii) Analysis of the costs involved and extra returns revealed favourable economics of the process.

5. TALO DURA PROCESS

5.1. Developed by Tate and Lyle in the mid seventies, for clarification of syrup after the evaporator, the process aims at improving the quality of sugar. The rationale behind this idea is the necessity of removal of impurities in suspension which owe their origin to the concentration of clear juice in the evaporator, and get occluded in sugar crystals during 'A' massecuite boiling. Studies on suspended impurities in white sugar manufacture by D.P. Kulkarni and V.A. Ketkar have shown three to five-fold increase in suspended impurities per 100 brix in syrup over those in clear juice. This is ascribed to mainly the precipitation of inorganic salts during clear juice concentration. Apart from this the suspended matter in clear juice also contributes to this problem. The syrup treatment by this process is equally applicable to raw-sugar manufacture by defecation as also to white sugar production by sulphitation of raw juice. The method of syrup treatment known as Talodura process is described as under—

5.2. The syrup from evaporator is treated with lime and phosphoric acid—the precipitate being removed by floatation employing aeration technique and special flocculant. The steps involved are as under—
(i) To the syrup are added lime and phosphoric acid, the dose of the latter being around 300 ppm. while the lime addition is regulated to obtain pH of 6.8 - 7.0. This results in formation of primary floes.

(ii) The treated syrup goes to aeration tank where it is impregnated with fine air bubbles.

(iii) To the aerated syrup is added a special flocculant ‘Talo dura’, which is a special polyacrylamide developed by ‘Tate and Lyle’ to serve as flocculation aid and bring about secondary flocculation of precipitate and air bubbles.

(iv) The syrup with the precipitate floes goes to special floatation clarifier with retention time of 20 minutes for separation of clear syrup from the precipitate.

(v) The clear syrup goes to pan boiling while the scum containing precipitate is sent to raw juice tank.

This process has been operated on large scale in some sugar mills and is reported to have given better performance in respect of

(i) colour of sugar,

(ii) loss in molasses which was reduced on account of lowering of viscosity in boiling.

5.3. In the ‘Blanco Directo’ process of Tate & Lyle for production of factory white sugar from cane-juice, the syrup clarification according to above method is combined with sulphitation of juice and separate treatment of filtrates from vacuum filter for avoiding recirculation. In effect the entire process comprises following steps.

(i) Raw juice is clarified by lime sulphitation and the heated juice settled in continuous clarifier, the clear juice being sent to evaporator and settled muds to vacuum filter as in conventional system.

(ii) The filtrates from vacuum filter which constitute 20% portion of the total juice processed in clarification and are presently recirculated via mixed juice are clarified by lime phosphate treatment and after aeration sent to a floatation clarifier. Addition of flocculant 'Talo sep' after aeration assists in floatation of precipitate scum. The clear liquid drawn from below goes to evaporator with clear juice while the scums are returned to vacuum filter station.

(iii) The syrup from evaporator is treated as described above and the scums from ‘Talodura’ process instead of being recycled are sent to the filtrate clarification section.

The special features of this process are—

(i) recirculation of impurities and nonsugars is eliminated both in juice clarification and syrup treatment.

(ii) lime phosphate treatment coupled with aeration and use of special flocculants and floatation in special clarifier in which the scums are removed from top and the underflow constitutes clear liquor.

(iii) The reactions in the process are all automatically controlled and the floatation clarifiers are designed by Tale & Lyle.
The advantages claimed are—

(i) better colour of white sugar 100-150ICUMSA units, and  
(ii) reduction in viscosity in final massecuite boiling with consequent better exhaustion of molasses and reduced loss in process.

6. SAHA JAIN PROCESS

Based on the principle of alkaline filtration of juice this process was an attempt to combine the essential good points in sulphitation and carbonation. Earlier Bogstra\(^8\) had attempted to combine alkaline filtration with sulphitation but the details of this trials are not available. Saha Jain process\(^9\) went through different stages from—

(i) filtration of sulphited juice of 10 pH and 95°C  
(ii) phosphatation of alkaline filtrates to neutral state  
(iii) lowering of temperature at filtration and neutralisation of alkalinity by phosphate and sulphur dioxide.

In its finally modified form the process as tried on large scale at some factories in India was as under—

The raw juice heated to 60°-70°C was sulphited as usual using 1.2-1.3% milk of lime of 20°-22° Bx. This neutral sulphited juice was pumped to liming tank where it was limed to 10.5 pH, and filtered in plate and frame type filter press. The alkaline filtrate with 500-600 mgm. CaO/litre, was partially neutralised to 9.8 pH by addition of clear extract of triple superphosphate in a treatment tank. This partially neutralised juice was sent to sulphitation tank for bringing down pH to 7.2 - 7.3 by the action of sulphur dioxide. The juice thus treated was heated to boiling temperature in juice heater and sent to continuous clarifier. The resulting juice was light coloured and brilliant in appearance. The settled mud was sent to raw juice tank.

The purity rise was higher than that with the conventional sulphitation process by 0.5 but the sugar produced was of superior quality with this process. The process was however abandoned after some trials by the factories due to the difficulties caused by

(i) stiffening of filter cloth which adversely affected the filtration rate  
(ii) batch operation of filtration of entire juice  
(iii) use of large quantities of chemicals.

7. ELECTRICAL PROCESS

Geerligs in his classical treatise on 'cane sugar and its manufacutre'\(^10\) brought out five decades back, mentions that several attempts were made to employ electricity for removal of impurities in cane juice, with all kinds of electrodes. In early fifties D.N. Ghosh,\(^11\) conceived the use of iron electrodes for electrolysis of raw juice preheated to
80°C whereby the lyophilic colloids which are negatively charged are precipitated partly due to contact with anode and partly by the gas bubbles generated. This resulted in rise in pH from 5.2 to 7.2 when the juice was withdrawn and filtered, the filtrate being neutralised with superphosphate. As this procedure involved very high consumption of iron, as well as electricity and gave rise to clear juice containing high iron content -10.2 mgm./100 gms. of clear juice, adversely affecting the sugar colour it was modified by Ghosh. In the modified form the process consisted in neutralising the preheated (70° - 80°C) raw-juice by lime to 6.8 pH and electrolysing the same as in earlier procedure. After ten minutes in the electroclarifier the juice at 8.3 pH was heated to 80°C and filtered, the filtrates being neutralised by superphosphate and filtered again. Pilot plant scale trials of this process were conducted at the experimental sugar factory of the Indian Institute of Sugar Technology, Kanpur. Colour removal in clarification was good and sucrose purity rise of 3-3.5 units was obtained but the iron content in juice of 3.5 mgm/100 gm., high electricity and iron consumption, proved to be the main obstacles in the way of adoption of this process.
CLARIFICATION

OTHER PROCESSES

1. C.F. Literature on *Ion Exchange Resins* from manufacturers.
7. Technical Brochure Tate & Lyle also M.C. Bennett W.S.J. Directory p.29-42.
10. H.C. Prinsen Geerlings *Cane Sugar and its Manufacture* p.146.
PART VI

EQUIPMENT EMPLOYED IN CLARIFICATION

1. The raw juice from the mill is received in automatic weighing scale and thereafter sent to clarification station. The entire clarification section comprises following units—

(a) Juice weighing,
(b) milk of lime preparation,
(c) juice heaters,
(d) juice treatment tanks,
(d) continuous clarifier,
(e) filter besides (f) SO₂ generation.

The juice weighing scale and imbibition water weighing scale are invariably located in the clarification section, though strictly speaking they do not form part of clarification process equipment. However the chemical control of the process of sugar manufacture requires the weighment of raw juice and the transport of cold juice to juice heaters to be scale as quick as possible, hence juice weighing scale is located in proximity to juice heaters.

2. JUICE WEIGHING

2.1. Three or four decades back the juice from the mill was weighed on platform weighing scales which were manually operated. This system being less reliable and laborious to operate suffered from the inaccuracies arising out of both human error and machine error, and was replaced by automatic juice weighing equipment. The design of juice automatic weighing scale incorporate—

(a) levers, and counterweights, or
(b) pneumatic operation.

22. Mechanically operated scales—The most common type prevailing in Indian Industry is the Maxwell Boulogne design operating on levers and counter weights. It consists of

(a) overhead juice receiving tank,
(b) weighing tank,
(c) system of levers, counterweight and valves for the two tanks,
(d) weighed juice receiving tank.

The top rectangular tank receives the juice continuously, which flows into the cylindrical weighing tank provided with a small vertical baffle at the conical bottom, with a hole, which retains certain amount of juice after the weighing tank is discharged and this arrangement helps maintain a constant tare weight. As soon as the tank is completely
discharged and the tare weight of weighing tank is reached, the counterweight which is in raised position, causes tilting of weighbeam thereby raising the empty weighing tank. The two valves of the top juice tank and weighing tank are fitted to a common steel rod in such a way that when upper one is open the other lower one is closed and vice versa and are operated only by the upward and downward movements of the weighing tank. Thus when the weighing tank is being discharged the inlet to the same is closed. A scale of this type usually is designed for 20-25 discharge tips in an hour. A totaliser or a digital counter is attached to all modern scales for indicating the number of tippings. The tare chamber has to be maintained free from dirt or bagacillo since if its hole is blocked the self taring system will not function and weights will be inaccurate.

2.3. Foxboro scale

—This weighing equipment consists of two juice tanks, operating in sequence such that when one is being filled, the other is discharged. The back pressure in the two tubes through which air is bubbled in juice tanks is exactly proportional to the weight of juice in the tank. During operation when a tank that is being filled reaches the predetermined weight the controller operates a three-way air-operated valve when the tank ceases to receive juice and discharges, while incoming juice drops in the second tank. The scale is provided with totalling counter and a recorder.

2.4. It is important to provide check weighing of the juice from the scale by installing a platform weighing scale on which is mounted a sloping bottom rectangular tank of capacity suitable for weighing juice from one tipping of weighing scale. Random checking of weights at least once per day is essential for good chemical control.

2.5. The weighed juice receiving tank should be cylindrical with conical bottom, having a capacity of $2\sqrt{2}$ times the volume of juice from one tipping. The tank bottom is connected to pumps through sand catchers. In view of the usual practice of adding phosphate to this receiving tank, the dosing of phosphate solution can be made automatic so that for each tipping of scale pre-determined volume of phosphate solution is fed to the receiving tank. The scales and the receiving tank are of M.S. construction and must be painted with acid resisting paint to prevent rusting.

2.6. It is very necessary to maintain proper sanitation at the juice weighing scale as also the juice receiving tank and frequent cleaning of the tanks with hot condensate coupled with spray of biocide is essential.

3. LIME PREPARATION

Since the lime is added to juice in the form of liquid calcium hydroxide slurry while the lime is brought to factory and stored in the from of lumps or as powder, the preparation of solution of lime known as milk of lime has to be carried out in the clarification station. In modern installations this station is located on the ground floor in close proximity to juice treatment tanks. The first step being slaking of lime usual practice is to install continuous rotary lime slaker on an elevated platform so that the milk of lime flows by gravity into storage tanks.

The lime cream discharged from slaker always contains grit and sand which can block
and damage valves and pumps so it is desirable to install a classifier or degritter in between the discharge end of the slaker and the lime cream storage tanks.

In the scroll type classifier, the lime cream from slaker is discharged into a tray with inclined bottom from where an inclined screw conveyor removes and carries the settled grit from the milk of lime, while it overflows into storage tanks. In another type of classifier the to and fro movement of slats removes the grit. In hydrocyclone the vortex generated separates heavy grit from the milk of lime.

The milk of lime is stored in M.S. tanks provided with slow moving stirrers.

4. PHOSPHATE PREPARATION

The modern trend is to use mostly phosphoric acid in dilute form or triple superphosphate solution. The triple superphosphate or T.S.P. is dissolved in hot condensate in a stainless steel or P.V.C. lined steel tank fitted with a stainless steel stirrer. The sludge is allowed to settle and the supernatant phosphate extract sent to a bigger storage tank which must be either P.V.C. lined or of S.S. From this storage tank which is located near the juice weighing scale the diluted phosphate extract is fed to weighed raw-juice. The pipes, valves, vessels and pumps must be of S.S. or P.V.C. or rubber lined to withstand action of acid.

5. TREATMENT TANKS

The old system of batch treatment of juice with lime, prevalent 3-4 decades back is now completely replaced by continuous treatment tanks which are suitable for both defecation and sulphitation processes of clarification. In some places only one tank is installed for juice treatment but it is preferable to have two tanks—one for treatment and the other to serve as correction tank.

In continuous treatment tanks lime dose is best controlled by pH controllers. Modern pH controller incorporates sensing of pH by Glass calomel electrode system. The electrode assembly converts pH into an electrical signal directly proportional to pH. The pH transmitter transmits the sensed pH to central station. In the event of deviation of measured value from the set value, control signals are generated. The lime feed actuator controls set of solenoids which in turn control the position of lime feed channel and regulate feed of lime to juice, through conical plug valve or any other type of valve which would adjust the opening of lime feed pipe. The lime flow control system designed and patented by the Central Electronics Engineering Research Institute, Pilani India, is in operation in many Indian factories operating the microprocessor based pH controller developed by this institute. This feed control system consists of a conical bottom cylinder which receives lime from bottom, the excess going back from the overflow into lime tank, Lime feed pipe opening is controlled by a conical plug moving up and down, the linear motion being imparted by a stepper motor. As the cone moves up or down the area of opening of the feed pipe is adjusted changing the lime flow rate.
6. JUICE HEATERS

6.1. As the name suggests, the function of the juice heaters is to heat the juice to the desired temperature. These are of three types

(i) tubular heaters,

(ii) direct contact heaters,

(iii) plate type heat exchangers.

The juice heating in clarification by defecation or sulphitation is carried out in two stages viz. primary heating of mixed juice before treatment and secondary heating of treated juice to the boiling point or slightly above that (100°C - 103°C). The plate type heaters are employed only for clear juice heating before it enters the evaporator. The medium for heating is usually—

(a) vapour from 2nd or 3rd body or vapour from last body and second body for primary heating, i.e. from 30°C to 70°C - 75°C,

(b) exhaust steam of 0.3 - 0.5 kg/cm² pressure or vapour cell vapours of 0.2 to 0.3 kg/cm² pressure or vapour from vapour cell and exhaust steam for secondary heating i.e. from 65°C - 70°C to 101°C. Whenever the vapours from two evaporator bodies are used as in case of (a) or combination of heating by vapours and steam is adopted, series heating in two heaters is resorted to i.e. two heaters operate in series, with partial heating being accomplished in each one. In order to achieve greater steam economy the present trend is to accomplish heating of the juice in both stages by vapours drawn from evaporator bodies. In a typical modern plant the juice heating is carried out in the following way—

1. Primary heating by last body vapour in a tubular heater installed in the vapour line of evaporator to condenser, upto temperature of about 45°C, and remaining heating upto 70°C by vapour from 2nd body, or—

heating the juice by vapours from 3rd body of quadruple or 2nd body of quadruple.

2. Secondary heating upto 90°C - 95°C by vapours from first body of evaporator or vapour cell and remaining heating by exhaust steam.

The series heating in two heaters requires high head at the delivery of the pump.

6.2. Construction—The tubular juice heaters are cylindrical shells fitted with tube plates at both ends. The tube plates are provided with baffles beyond the tubes so as to divide the two end portions of the heater into compartments. The compartments of juice entry and exit have only one pass while the remaining compartments have two passes viz. upward and downward flow. Multiple circulation of juice is achieved by providing double the number of tubes in each compartment, i.e. for 12 tubes per pass the compartment will be fitted with 24 tubes. The shell, headers and tube plates are of mild steel construction but stiffeners are welded to the covers to enable them to withstand high pressures. These covers are hinged to the body of the heater and closed by hinged bolts of sufficient strength to hold the covers under pressure. In the case of vertical heaters the doors are
balanced by counterweights to facilitate smooth operating and closing. The juice heaters are equipped with two doublebeat valves, according to practice followed in India, and usually the same heaters are operated for raw and sulphured juice on alternate days to prevent accumulation of scales. The doors are provided with cocks, one for each compartment.

Solid drawn brass tubes of 42 mm. inside diameter and 1.5 mm thickness are common in Indian Industry. The length varies from 3 to 4 meters. Few factories have reported use of aluminium tubes for raw juice heating but this has not gained popularity. The juice velocity is about 1.8 to 2 meters per second. Higher velocity of juice is conducive to higher rate of heat transmission. The steam or vapour connection is provided in the upper half of the shell about one fourth the height from top of the heater, in the case of vertical juice heaters to facilitate draining of the condensates. With horizontal heaters the steam entry is close to one end of shell. The incondensible gas vent is open to atmosphere when steam is the heating medium but when bled vapour is to be used, the vent pipe has to be connected to vacuum system. The incondensibles should be drawn from top as well as bottom of the shell. The condensates are removed through a pipe connected to a pump.

The heat transmission from heating vapour to juice is affected adversely by scale on the heating surface of the heater, which gradually builds up during running. The total installed heating surface of juice heaters, in modern plants is around 6.5 - 7 m²/tch divided into 5 heaters one of which is always under cleaning.

6.3. Vapour line juice heater is installed in the vapour line of the last body of evaporator before the condenser for cold juice heating. Since the vapours are of low temperature, with consequent small temperature difference between cold juice and vapours, i.e. 20°-30°C the net rise in temperature of the juice is of the order of 10°-15°C if the juice heater is properly designed. Some technologists have obtained good heating with heaters of shorter tube length than with normal juice heaters. This system results in good saving of steam and reduces load on condenser.

6.4. Direct vapour contact heater—This is akin to a condenser which condenses vapours from an evaporator body in the cold juice by direct contact, and has found acceptance in Australian Sugar Industry. When installed in the vapour line of last body, partial heating of cold juice is achieved, the remaining being accomplished in conventional tubular heater. However if the same is positioned so as to utilise vapours from last but one body or 3rd body of a quadruple complete primary heating of raw-juice to 70°C is achieved. Despite the dilution effect of juice on account of condensed vapours definite steam economy is effected. Moreover the heating is more efficient with direct contact, in a properly designed condenser than in tubular heater. Other advantages are less maintenance, no scaling problem and low cost of equipment.

In the D.C.V.H. at Fairymead Mill in Australia, the cold juice inlet is through a distributor mounted circumferentially on the outer surface and the juice enters through slots. This juice passes through a rain tray to contact vapour in counter current fashion. The incondensable gases are removed from top of the heater and juice is discharged
through a barometric column of 11.9 meter in height into a seal pit within a juice tank. In India, vapour contact heater has been installed at Bobbili for heating clear juice fed to evaporator by vapours from vapour cell. The temperature rise was 5°-7° and dilution about 3%. In U.P. some factories have made use of vapours from different evaporator bodies for heating raw juice in direct contact heaters.

7. CLARIFIER

7.1. The function of the clarifier is to separate the precipitate and the clear juice from the treated and boiled juice employing the principle of subsidence and decantation. All modern multitray clarifiers are continuously operating type and despite their different designs have some common features like withdrawal of juice from top sections of compartments, and mud from bottom portion as also cylindrical construction. The compartments are formed by trays sloping either towards the centre or towards the periphery. The muds settled on the trays are drawn by revolving scrapers towards mud outlet.

7.2. Dorr clarifier—By far the most favoured clarifier in Indian industry, the Dorr clarifier which was introduced nearly five decades back, has undergone modifications over the decades in design the latest model being Rapi Dorr 444. In this design the cylindrical clarifier is divided into four compartments with juice inlet, clear juice and mud withdrawal being arranged in every compartment, virtually making the unit function as four independent clarifiers encased in one cylindrical vessel. A central hollow shaft carries rotating scrapers for each compartment tray which scrape and move the settled mud into mud boot. The juice from secondary heater enters a flash tank located above the clarifier, which allows the air and vapour to be driven out through the top pipe. From the flash tank juice enters the feed chamber or flocculation compartment through tangential inlet. The feed compartment with half the diameter of the clarifier, is provided with special scraper to drive the light scum which rises to the top and flows into mud collection box. The treated juice enters each compartment through the openings of the rotating centre tube, and flows outwards at decreasing velocity creating minimum turbulence. The clear juice draw off is arranged circumferentially from a number of openings in a pipe running along the periphery of each compartment and the clear juice from each compartment flows into a clear juice box mounted at the top chamber, through vertical pipes. The mud from each chamber is scraped by rake arm and collects in the mud boot, and the mud from all compartments is led to a mud box with the help of diaphragm pump. The mud box like the clear juice box is located at one end of the top of the clarifier so that mud flows by gravity to the filter station. Likewise the clear juice goes to the evaporator through a tank and pump or a standpipe connected to pump. Manipulation of the telescopic juice valves in the clear juice box enables alteration in proportions of juice withdrawal from different compartments. The speed of stirrer is usually adjusted from 1 rev. in 12 minutes to 1 in 30 minutes. In the event of poor settling of muds lower speed is preferred. Vents are provided for each compartment for escape of the trapped vapours of gases. Usually at full rate of crushing the withdrawal of clear juice and mud are by overflow only but when working at lower rates of crushing than the one for which the clarifier is designed the juice is withdrawn from the sump tank provided at the low end of the settler. Good lagging prevents fall in temperature of juice even during stoppages.
7.3. **Graver subsider**—Latest design of this type of clarifier known as Prima Sep, unlike the Dorr clarifier incorporates peripheral feed and withdrawal of clear juice near the centre. The treated juice enters the top feed chamber which has tray sloping towards the centre. This chamber known as primary mud chamber where the mud scraped from the tray collects in a special mud sump which is connected to main mud sump at the bottom of the clarifier. The remaining trays are however slanting towards periphery and successive lower tray is smaller in diameter than the tray above it. The clear juice is withdrawn from the central zone where the velocity of juice is maximum. The design is based on the concept of upward sludge filtration and the precipitate descends down the peripheral area where the juice velocity is minimum. The mud thickens as precipitate has a large area for falling to the bottom from the top sloping trays.

7.4. **Other clarifiers**— Bach clarifier is characterised by peripheral feed and tray sloping towards the centre. The small bottom portion serves as thickening compartment. In the later design the cylindrical clarifier contains vertical pipes with large number of settling chambers. The settling units known as 'poly cells' which are concentric circles are located in the upper portion of the clarifier. The cones open at the bottom, serve as independent settling units as the clear juice flows out through the top and mud slides down into the bottom mud chamber. The juice retention in this type of clarifier is reported to be much less than in the conventional designs.

7.5. The scrapers provided in the clarifier must effectively remove the mud from the trays as accumulation of mud will result in microbial accumulation which will increase sucrose losses in process. The flash tank, through which the heated juice is passed into the clarifier must be free from obstacles inside for vapours to be released. Similarly care has to be taken regarding the position of flash tank with regard to height from clarifier and discharge pipe of juice.

7.6. **Tray-less clarifier**— The multi-cell clarifiers suffer from the main disadvantage of long time of retention of 3-4 hours due to large hold-up which involves the risk of decomposition of sugars due to combined effect of time and temperature. Hale and Whayman\(^9\) in Australia developed an altogether new design of a single tray clarifier to eliminate the drawbacks in the multicell subsiders viz.,—

(i) disturbance in settling and hence lower rate of separation of precipitate,

(ii) multiple compartments,

(iii) risk of mud accumulation

(iv) large juice hold-up.

They developed a new single tray or trayless clarifier which essentially eliminated the above shortcomings by incorporating—

(i) only one cell and tray for settling,

(ii) entry of treated juice by circular channel approximately in the region half the height of the vessel,

(iii) withdrawal of clear juice by circular channel.
(iv) Peripheral multipoint feed entry
(v) addition of flocculant.

The treated juice is fed to the subsider annular launder at two diametrically opposite points, the outer edge of the launder being above the liquid level. The inner edge of the circular feed well is castellated for distribution of feed evenly. Rotating scraper removes sand or settled solids through slots provided at the inner edge of the feed launder. The descending juice from the feed well is radially deflected by ring shaped baffle mounted on rotating scraper. The clear juice draw off is also arranged through annular channel. The bottom portion of the subsider is a shallow cone and a mud boot into which the mud is dropped by a special rotating rake which covers the entire sloping surface. Flocculant addition and optimum doses of chemicals are essential. The juice residence time is reported to be as low as 12.5 minutes and the mud density satisfactory. The pH drop of limed juice was observed to be 0.1 only. This single tray design clarifier is reported to be working satisfactorily in sulphitation factory in Indonesia with one hour’s retention of juice.

1.1. The clarifiers have to be lagged thoroughly so as to minimise drop in temperature, which is usually observed to be 5° - 7°C under good operating conditions. In the case of multicell or any type of subsider following points need special attention.

(i) the juices have to be treated with optimum doses of lime and phosphate,
(ii) the treated juice must be heated to boiling,
(iii) location of flash tank must be well above the clarifier and vapours must be seen to be flashed.
(iv) the flocculant addition to treated juice should take place after the flash tank prior to entry of juice to clarifier and proportionate to the juice flow
(v) incondensable gas outlets of the subsider must be functioning
(vi) the scrapers provided must scrape the mud from the trays as accumulation of mud in certain pockets would lead to bacterial development and loss of sugar.
(vii) the juice and mud withdrawal from subsider must be smooth and must keep pace with the quantity of feed.
(viii) thorough cleaning of clarifier after draining it once in 40-50 days is essential to prevent build-up of mud pockets.

Installing circular pipes with a number of openings, along the periphery of the top of each compartment of a clarifier, in place of the existing clear juice take off arrangement has yielded good results in respect of mud settling and capacity of the multicell Dorr clarifier in many Indian Factories.

It is desirable to strain the clear juice using a stationary or vibrating stainer with very fine openings, at the juice outlet of clarifier.
8. FILTERS

8.1. The muds from settlers contain 5-7% precipitate in suspension and juice has to be recovered from the same, by filtration. The filters perform the task of eliminating precipitated matter from the settlings of the clarifier, with minimum loss of sugar, by separating the mud from feed and applying wash water. The muddy juice has to be at high temperature (above 80°C) since viscosity of juice is inversely proportional to temperature and low viscosity favours filtration. Two types of filters are employed in mud filtration in cane sugar factories, viz.

(i) pressure type filters or filter presses

(ii) continuous vacuum filters out of which the latter type are most common in modern plants.

8.2. Filter presses—This is the oldest type of equipment working in batch system in sugar manufacture. Filter press consists of a series of plates and frames mounted on two bars, which slide and can be pressed firm by screw device or hydraulic pressure. The plates are dressed with cotton or nylon cloth and the press closed followed by tightening. Mud is pumped into the press and it traverses the cloth and the insoluble precipitate i.e. the cake accumulates between the cloth and the frame.

The clear juice flows down the ridges into a gutter through cocks. After the press is filled with cake the pressure on the pump rises and the wash water pump is started followed by steaming for draining the liquid. The press is then opened and cake dropped. Filter press operation yields clear juice and filter-cake of 3-6% sugar.

8.3. Continuous vacuum filters—

8.3.1. Oliver Campbell vacuum filter is the most common filter in the sulphitation plants of India. Essential components of this filter are—

(i) bagacillo mixer

(ii) mud trough

(iii) rotary filter

(iv) filtrate receiving vessels and pumps

(v) vacuum pump.

The mud to be filtered flows by gravity from the clarifier to a mixer fitted with stirrer and bagacillo from mill bagasse carrier is fed continuously for mixing with the mud. From the mixer mud mixed with bagacillo is continuously led to the mud trough provided with an agitator oscillating to and fro to prevent settling of mud in the trough.

The filter drum rotating around horizontal axis is always partially submerged in the mud of the trough. It is a horizontal cylinder with corrugated surface which is covered by 24 fine copper or stainless steel screens, each one forming a segment connected to vacuum system through tubes. The segments are equally spaced and each one occupies an area corresponding to 15° of the circumference, along the entire length of the drum. Small
metal tubes connect the revolving segments individually to the stationary distribution valve, through which filtrate withdrawal pipes are drawn and led to filtrate connecting vessels under vacuum. The screens have 625 perforations per sq. inch i.e. 95/cm² each with an opening of 0.5 mm. dia. The drum drive is provided by a constant speed motor through reduction gear and V. belt, with arrangement to vary speed from one revolution in 3 to 10 minutes. The vacuum generating system consists of either—

(i) barometric condenser coupled with air pump or

(ii) liquid ring vacuum pump most common being 'Nash' type.

The bagacillo supplied to the mud mixer is conveyed by a blower from underneath a screen fitted to the bagasse carrier. In some factories a vibrating screen is installed at the exit of the last mill, for recovering bagacillo. The screen can be 8 to 14 mesh depending on the bagasse moisture and fineness. But the bagacillo required for proper filtration varying from 6 to 10 kg. per tonne cone is to be separated and supplied to the filter station.

8.3.2. **Operation**—The mud tank receives the mixture of mud and bagacillo which acts as filter aid, and the drum as it starts revolving in the mud tank, under low vacuum (250-300 mm) sucks the mud through the lower sections which are immersed in the mud. This surface is thus coated with suspended mud and bagacillo. The juice thus drawn known as cloudy filtrate contains fine mud in suspension and is turbid in appearance. This portion of the drum with its mud coating, passes to higher vacuum zone viz. 300-450 mm. where the filtered liquor is less cloudy. The juice from this zone is known as 'clear filtrate' though it is not clear but less cloudy. This stage is followed by washing of the cake as the sections coated with cake move upwards and meet the atomised spray of hot water.

This cake washing is continued further as the cake travels further and receives water dripping from the sheet distributor. All this washing effectively desugarises the cake and the light filtrates are sucked by vacuum. After washing, the sections, with cake formed, pass further towards the scraper and enter the no-vacuum zone. The stationary scraper easily detaches the cake along the entire length of the drum. After the scraping the drum enters the mud trough again and the cycles of mud pick up, high vacuum sucking and washing go on continuously. The filter cake leaving the drum contains about 1.5 - 2% sugar and 75-80% moisture. The quantity of filtercake is around 3.5% on cane and is much higher than the press cake from filterpresses on account of the presence of added bagacillo and high moisture. The thickness of cake under normal conditions is about 6-10 mm.

The filtrates are of lower purity than the clear juice by 1.5-2 units on account of dissolution of non-sugars during washing. The water should be of 70°-80°C and is used to the extent of 3-5% on cane, the normal practice being to use hot condensates.

Mud retention is the dry solid retained by filtercake per hundred dry insoluble solid contained in the mud fed to the filter. Mud retention varies from 50-75% under different operating conditions and high mud retention can be obtained by—

(i) good settling characteristic of mud—5-7% mud solids in feed,
(ii) correct proportion of fine bagacillo-mostly between 8 mesh and 20 mesh,

(iii) good vacuum conditions.

(iv) lowest possible speed of filter drum 1 revolution in 7-10 minutes.

Hugot favours bagacillo of fibres of 3 cm. length and 1.0 mm in diameter. Too fine bagacillo containing pith or too coarse bagacillo with long and thick fibres is not conducive for obtaining good results with respect to mud retention and purities of filtrates. It would be good practice to fit a series of 6; 8 and 10 mesh screens on the mill bagasse elevator, the area depending on the bagasse fineness as well as actual requirement of bagacillo. Mud retention at Yeshwant factory was found to be 65% with Oliver filter, while handling sulphitation muds. Addition of flocculants to bagacillo mixer is recommended for improving mud retention and filter efficiency.

For sulphitation plants in India the filtering area of 0.5-0.7 m²/tch is considered adequate for normal operation.

8.4. Other filters—

8.41. Eimco continuous vacuum filter operates more or less on the same principle as the Oliver Campbell filter, but the design incorporates some special features such as—

(i) Hy-flow valves for filtrates, large ports provide streamlined passage for flow of filtrates from the drum.

(ii) Polypropylene grid supporting fine stainless steel screens offers greater area for filtrates.

(iii) The drum submergence is adjustable from 10-30% in the trough.

(iv) Steam pipe is located under the filter cake scraper and the steam blown on the revolving screen prevents wax build up on screen perforations.

8.42. Eimco belt filter—This rotary vacuum filter has the drum covered with polypropylene cloth which passes around a roller where cake is discharged. The cloth is cleaned by jet spray of water before it returns to the trough but after the discharge of the cake the wash is collected in a trough underneath the wash roller, and sent back to process for use as imbibition water. The flocculant separan AP-30 is added to the mud bagacillo mixture prior to its entry into the mud trough. The cloth needs to be changed after 4-5 months operation. For maintaining cloth in good condition, the wash water applied has to be of 3kg/cm² and 82°C.

Conversion of ordinary Eimco filter to Eimco belt filter is reported to double the capacity.

8.43. Rapifloc system—The Rapifloc continuous rotary filter developed by Dorr Oliver permits filtration through highly porous cloth fixed over the existing perforated screens, using bagacillo as filter aid. The mud is limed to 7.5 pH and special flocculant like Separan AP 30 added in a special vessel to improve compactness and floc characteristics. From this coagulator the mud flows by gravity into the filter mud trough. The thick cake is detached by scraper and cloth washed by special high pressure water jets under a
special cover. Substantial increase in capacity with this system over the old established system is claimed.

8.5. Miscellaneous—

(a) The filtrates are usually returned to raw juice receiving tank which constitutes an extra load on the clarification system which is certainly undesirable, but is unavoidable since the filtrates cannot be sent to evaporator on account of the presence of insoluble impurities (1-2%). An ideal method would be to treat separately these filtrates by—

(i) chemical treatment followed by

(ii) heating to boiling and settling in separate subsider.

Tate and Lyle have developed system of separate clarification of dirty filtrates employing phosfloatation principle which is described separately.

(b) The filtrates from the mud filtrations, are collected in two vessels connected to pumps and the system upto the pump discharge is under vacuum. Any vacuum leak in this system has been found to result in entrainment i.e. to carry over of filtrates to the condenser. The filtrate pipes should preferably be of PVC or S.S. or copper and the height of filter from ground floor nearly 4-5 meters.

(c) During shut down or stoppages the filter must be thoroughly cleaned and surface steamed to clean and disinfect the filtrate passage pipes and drum surface.

9. PLATE TYPE HEAT EXCHANGER

These are installed essentially for heating clear juice from about 95°C to the operating temperature in the vapour cell i.e. 105°C - 108°C. A plate type heater consists of thin corrugated sheets separated by gaskets fitted in an adjustable frame. By virtue of thin film of juice in each pass, the heat transfer from steam is very efficient. This unit has the merit of being compact, requiring less heating surface than tubular heater and being more efficient than the latter for clear juice heating. Care has to be exercised in regard to selection of material for gasket and the pressure of juice in the case of this heater.
EQUIPMENT

8. Literature on clarifiers of different designs.
MAXWELL BOULOGNE

Juice weighing scale.

Fig. 1.
Fig. 2.

JUICE HEATER
Fig. 3.

Sulphur burner continuous.
SULPHUR FURNACE

CIRCULATION PUMP

QUAREZ SULPHUR FURNACE

Fig. 4.
EXISTING SULPHUR BURNING SYSTEM

Fig. 5.
STAR DISTRIBUTOR

Fig. 6.
JUICE SULPHITATION TANK

Fig. 7.
CONTINUOUS JUICE SULPHITATION TANK

Fig. 8.
DORR CLARIFIER

Fig. 9.
Fig. 10.
TRAYLESS CLARIFIER

Fig. 11.
PREPARATION MILK OF LIME

Fig. 12.
5. EVAPORATOR

PART-I

1. The clear juice contains about 83 to 85% water, the remaining portion being represented by the sugar and impurities known as nonsugar components. Most of this water has to be removed for sucrose crystallisation and instead of evaporating all the water necessary for sucrose crystal recovery in one stage, for the sake of economising the energy consumption an ingenious method was evolved to first get rid of nearly 75% of the water in clear juice in the most economic way and send the concentrated juice known as syrup with 35-45% water to pan station. The evaporator station which performs the function of concentrating the clear juice to syrup of 60-65% solid content has the most important role to play in the energy saving in the entire cane sugar manufacturing process.

Before the advent of machine age, the sugar was crystallised from cane juice by boiling it in open pans heated by fire. In 1812 and 1813 Howard patented the use of steam and application of vacuum boiling to concentrate juice. In the next phase in 1833 Degrand in France, developed double effect evaporator in which latent heat of vapour was used for boiling. The final phase of evolution of the evaporator system was marked by the revolutionary device of multiple effect evaporation and use of vapours for pan boiling introduced in 1900, the credit for which belongs to Robert Rillieux. In all sugar plants multiple effect evaporators are installed the number of vessel being usually 4 or 5.

The object of evaporator station is to reduce the water content of clear juice to a level where the sugars are still in the dissolved state i.e. the solution is unsaturated with respect to sucrose. In practice for the factory white sugar process the limit of evaporation corresponds with concentration of juice to syrup of 65° Bx and usually the syrup proceeding from the evaporator stage has a brix of 60°-65°. Thus out of the water to be evaporated for sugar crystallisation nearly 80-85% is removed at evaporator stage.

2. PRINCIPLES OF EVAPORATION

2.1. In any liquid, when heat is applied the molecules are put into violent motion and in the case of juice which is a solution of sugars and other soluble components in water, the same principle holds true. In water the liquid molecules are constancy in motion and at the surface, the molecules are trying to escape while at the same time surface is being bombarded with molecules of steam and air. When heat is applied to this water the molecules in liquid move more violently with the result that the molecules at the surface will overcome the pressure of steam or air molecules which are bombarding the surface the net effect being escape of molecules from the liquid. Thus if pressure at the surface of
water is reduced, i.e. suction is applied, escape of molecules from the surface will gain momentum. Water boils at 100°C under atmospheric conditions but with reduction of pressure i.e. by application of vacuum the temperature of boiling is lowered but if the pressure is raised the boiling point rises. The boiling points of water at different temperatures and pressures are contained in the steam table. As far as the multiple effect evaporator operation in sugar industry is concerned the relevant data relating to boiling point of water at different pressure is given in Table 1.

2.2. Boiling point elevation—In the case of juice which can be considered to be a solution of sugar in water, the temperature of boiling is somewhat higher than that of water under same conditions of pressure. This is referred to as elevation of boiling point or boiling point rise. This B.P.R. depends on concentration of sucrose as also the impurities contained in solution. In general—

(i) the B.P.R. rises with brix of juice or syrup.
(ii) the B.P.R. is higher, higher the impurity level i.e. as purity of sugar bearing material goes down, the boiling point rise increases. The enclosed table 2 gives data relating to the B.P.R. at different purities and brixes.

This table gives the B.P.R. at atmospheric pressure and the effect of variation of pressure has negligible effect on the B.P.R. values.

2.3. Effect of hydrostatic head—In a column of boiling liquid, the pressure at the depth of say one meter is equivalent to that at the surface plus the pressure exerted by one meter of the liquid. This is termed as hydrostatic head which assumes importance in liquids boiling in tubular calandrias wherein the heating medium i.e. steam or vapour is fed to space surrounding the tubes while the juices or syrups boil in tubes. This hydrostatic head has pronounced effect in the boiling of juices or syrups as the brix of material or density goes on increasing progressively in boiling and it plays a vital role particularly in the pan boiling as the boiling point of liquid increases with hydrostatic pressure. In a well designed multiple effect evaporator, the juice is expected to boil throughout the length of the tube, the juice layers at a depth of say half a meter will boil at temperature corresponding to the pressure at the surface of the tube increased by the hydrostatic head equivalent to half a meter of juice height and the mean hydrostatic head may be taken as corresponding to one fourth of the height of the juice column. The increase in hydrostatic pressure can be calculated by multiplying depth of liquid column by the density of the liquid. Table 3 deals with increase in boiling point due to hydrostatic head for some juices and massecuites.

3. WATER TO BE EVAPORATED

3.1. The total water to be evaporated in an evaporator can be calculated from the brixes of entering juice and the syrup leaving the system, the main basis being that the solids in solution remain unchanged.
If \( B_1 = \text{Brix of clear juice entering} \)
\( B_2 = \text{Brix of syrup leaving} \)
\( W_1 = \text{Weight of clear juice % cane} \)
\( W_2 = \text{Weight of syrup % cane} \)
\( E = \text{Quantity of water to be evaporated % cane} \)
\[ W_1 \times B_1 = W_2 \times B_2 \text{ since the quantity of solids in solution is constant.} \]

\[ W_2 = \frac{W_1 B_1}{B_2} \]

and \[ E = W_1 - W_2 = W_1 \left( 1 - \frac{B_1}{B_2} \right) \]

If juice brix is 15° and syrup Bx 60° for 100% clear juice on cane water evaporated will be—
\[ E = \left( 1 - \frac{15}{60} \right) \times 100 \quad \text{i.e.} \quad 75\% \text{ cane}. \]

Steam being the heating medium for juice boiling some aspects of the properties of steam, have to be clearly understood in so far as they relate to the evaporator working.

(a) If the juice enters the evaporator at lower temperature than that obtaining in the vessel some heat will have to be given to it to raise the temperature to boiling point, which can be calculated as—

\[ H = W_1 \times S \times (t_1 - t_2) \]

Where \( H = \text{heat to be supplied in Kcal/g.} \)
\( W_1 = \text{Wt. of clear juice} \)
\( S = \text{Sp. heat of juice} \)
\( t_1 = \text{temperature of boiling juice} \)
\( t_2 = \text{temperature of juice entering} \).

3.2. When the juice is already at the temperature of boiling liquid in the vessel it is entering, latent heat required to vaporise the water will have to be supplied to it. If it is at lower temperature than the B.P. it has to be heated to boiling temperature and thus the total heat involved will be sensible heat plus the latent heat of vaporisation which can be calculated by Regnault formula taking 0°C or 32°F as datum point \( \lambda = q + r = 607 + 0.3 t \) in m-units where \( \lambda = \text{total heat to be supplied to unit weight of water to convert it from 0°C to steam.} \)

\[ q = \text{sensible heat required for heating unit weight of water from 0°C or 32°F to boiling point} \]
\[ r = \text{latent heat of vaporisation of water} \]
\[ t = \text{boiling point of water at a particular pressure.} \]

All heat units are expressed as Kcal/kg or BTHU/lb.

4. MULTIPLE EFFECT EVAPORATION

The concept of multiple effect evaporation developed in the early part of nineteenth century by Robert Rillieux is based on the use of vapour of boiling juice for evaporating further the same juice in another body. This way 2, 3, 4, 5 or 6 vessels can be joined together with the first one heated with steam. The pressure in each vessel in the series goes on gradually decreasing, whereby the boiling point of juice is also diminishing progressively as we pass from first vessel to the last one which has its vapour space connected to the vacuum system. Thus if the first vessel in a quadruple effect is heated by steam of 110°C, the vapoars at about 100 - 103°C from this will be connected to the heating space of the second vessel which will have vacuum of say 200 mm, in the same way the vapour of the second vessel boiling will be led to heat 3rd body with around 400 mm vacuum while the last body will be boiling at 650 mm vacuum. In this way even though more boiling vessels have to be installed the system offers three main advantages viz.

\( (i) \) steam economy since one kg of steam is utilised for evaporating 4-5 kg of water from this system.

\( (ii) \) exposure of juice to high temperatures for longer duration is avoided, thereby reducing sucrose destruction to minimum.

\( (III) \) Vapour from any vessel can be robbed for heating of juice or pans, operation thereby reducing the steam load in the process of sugar manufacture.

5. LIMIT OF TEMPERATURE FOR STEAM AND VACUUM

When juice is boiled in tank the heat is transmitted to it first from steam to metal and through the metal to the juice boiling inside the tank. Saturated steam is ideally suited for this heating in view of the good heat transmission obtained. On the other hand the super heated steam gives poor heat transmission. Nevertheless slight super heat would not affect the heat transmission and Webre and others have as a result of experiments conducted by them shown that super heat upto 37°C would not have adverse impact on heat transmission. According to Hugot 10° - 30°C super heat should not present any problem of heat transmission.\(^{2}\)

The heat transmission will always be higher with high pressure steam at higher temperature as heating medium but this aspect calls for cautious approach in view of the danger it would pose from the point of view of inversion of sucrose and formation of colour on account of contact of juice with high temperature. Normally pressure of 1 Kg/cm\(^2\) steam at temperature of 120°C for 1st body of a multiple effect evaporator should be considered to be upper limits of pressure and temperature. The same temperature and pressure limits may be observed for vapour cell or pre evaporator body. Each factory however should decide upon this limit by estimating the inversion taking
place under different conditions of steam pressure and temperature. It is important that with very short boiling time of 1-2 minutes high pressure steam upto 120°C should be acceptable. The last body of the evaporator is connected to condensor and is boiling under vacuum of 625 - 650 mm at a temperature of 55° - 57°C. Higher vacuum in last body than 625 mm is not recommended as a precaution against carry over of boiling liquid in the last vessel commonly known as entrainment.

6. EQUIPMENT

6.1. In a single effect evaporator the steam is supplied to steam space and the juice boiled in the vessel, while in a double effect evaporator die heating by steam is accomplished only in the first vessel while the 2nd vessel boils on heat furnished by the vapours from first vessel and juice after concentration in the first vessel flows constantly into 2nd one, boiling in it under less pressure than in the first one. Likewise there are three, four, five and six vessels connected in series, commonly known as triple, quadruple, quintuple and sextuple. By far the most commonly installed evaporator is a quadruple in the sugar industry though quintuples are being used in some factories. For effecting further economy in the steam usage in process, vapours from the multiple effect evaporator are employed for heating and boiling pans in two ways:

   (i) Robbing vapour from different bodies of evaporator.

   (ii) Installing a preevaporator or vapour cell, the vapour from which is entirely used for process operation while the concentrated juice passes to the multiple effect system.

6.2. System—The evaporator station is usually located 6-7m above the ground floor and essentially consists of following units—

   (i) Evaporator bodies
   (ii) Condensate pumps connected to calandrias
   (iii) Syrup withdrawal pipe connected to pump
   (iv) condenser
   (v) steam connection with valve
   (vi) piping connecting the juice space of bodies
   (vii) vapour pipe from each body
   (viii) the clear juice feeding arrangement.

   The clear juice enters the first body heated by steam and gets progressively concentrated from first to last body to syrupy consistancy, syrup being withdrawn from last body. The vapours from first vessel are connected by pipe to heating space of the second and in this way upto the last body the vapours from previous body are used for boiling. The last body vapours are condensed in water in a condenser connected to the vapour space of the body.

6.3. Construction—A body of multiple effect evaporater consists of two main cylindrical
structures, the lower one being the calandria while the upper one fitted to it is the vapour body. The calandria is of mild steel cylindrical construction with open tubes fixed at two ends into the mild steel plates.

(a) The calandria is provided with a vapour inlet,

(b) pipe connection for evacuating condensate etc.

(c) incondensible gas removal pipe.

The upper body also fabricated of mild steel is cylindrical in shape and has at the top a conical upper dome with a 'save all' and a vapour outlet. The function of 'save all' is to arrest the juice droplets carried away by vapour. The height of the body above calandria is usually 2-2.5 times the calandria height for preventing entrainment of juice. The bottom of the evaporator vessel is an inverted cone also of mild steel construction, fitted by means of bolts to the lower part of calandria. The fittings of the bottom include a door, juice inlet connection, and in some designs even outlet connections. The boiling juice is circulated vigorously through the tubes and the bottom saucer while the vapours formed are released through the vapour space of the body. The steam or vapour is admitted in the space of the calandria, surrounding the tubes.

The calandria shell is usually fabricated from 12 mm thick m.s. plate while the tube plates are of 25 mm thickness and it is usually joined to the upper body as well as bottom saucer by flanged joints and bolts. Vertical baffles are fitted in the vapour space of the calandria to serve as guides for distribution of steam or vapour throughout the vapour space. A centre well with 1/8 to 1/4 the diameter of calandria serves to provide downward passage for juice rising from bottom through the tubes and is known as central downtake. In some designs the downtake is in the form of lateral well but the function is the same viz. to aid circulation of juice in the calandria. The tubes of calandria are usually of brass of 70% copper and 30% Zinc or 70% copper, 29% Zinc and 1% tin. The tubes with length of about 2 metres are expanded at the tube plates and need to be annealed at the ends, to prevent cracking after expansion. The tubes of 42 mm inside diameter with 1.5 mm wall thickness are normally fitted in evaporator bodies in Indian industry. Stainless steel tubes have been introduced recently and are considered to be good for operation but are not common in India. Maximum number of tubes have to accommodated in calandria for achieving good heating surface per unit area of tube plate. Condensates are drained through pipes connected to lower tube plate of calandria and the pipe is connected to suction of pump. The condensate pump body should be connected to the top of calandria by means of small pressure equalisation pipe.

The incondensible gases owe their origin to

(i) gases or air contained in the juice which are released on boiling

(ii) air leaks through joints.

The gases have to be removed, since their accumulation in the calandria leads to poor heat transmission particularly in the last two bodies. In the first body heated by steam a small pipe from calandria from a point farthest from the steam entry will vent the incondensibles to atmosphere. On the other hand in other bodies heated by vapours, the
incondensible gas withdrawal pipes are located in such a way as to ensure proper distribution of vapour in the calandria. Air being heavier than steam, accumulates at the bottom of calandria and some incondensible gas pipes pass through the calandria to tube plate and terminate 100 mm from the bottom of lower tube plate. Thus some gases are vented from top portion and heavier ones removed from bottom. The gas outlets are connected to a common pipe inside the vessel, which is taken out of the vessel and connected to vapour space of the same body. A cock provided in the vertical pipe outside the vessel is operated as per requirement for venting out gases.

6.3. Juice Connections—Juice feed to each body is arranged in different designs of evaporator in the following ways—

(i) In most of the designs the outlet from one body is passed through a pipe to the saucer bottom of the next vessel and connected to a circular distribution ring with slots or holes, fitted in such way as to direct the juice to the tubes.

(ii) In some evaporators the centre well is sealed at the bottom and connected through a funnel to juice outlet pipe of the body. Thus juice or syrup flowing into this downtake inevitably goes out of the body and is not recirculated. The juice inlet is provided at the bottom and if the incoming juice is properly distributed along the periphery of the bottom tube plate the circulation of juice is expected to be quite satisfactory.

Valves are provided in the juice connection pipes between two vessels, which can be operated from the evaporator floor.

6.4. Vapour space—In the upper part of the body of evaporator about 25-30 cms above the calandria a manhole is provided to enable a worker to enter the body for cleaning. Sight-glasses are fitted at the working front and at the back of each vessel for observing the juice boiling inside as also the level of juice.

Vapours escaping from the boiling juice invariably carry with them small droplets of juice and as these fine droplets are light in weight they are entrained in the vapour and can pass to the calandria of succeeding body or to condenser unless separated and recovered. The velocity of vapour goes on increasing from first to last body and hence the chances of carry over are greater toward the syrup end. One method of reducing entrainment is to increase the height of vapour space but this method alone will not prevent entrainment and special entrainment arresters as 'save all's are installed in the vapour outlet of the body. They are designed on the principles of—

(a) sudden change in the direction of flow

(b) change in the velocity of vapour,

(c) obstruction to the flow of vapour

(d) centrifugal force.

Entrainment prevention is important for three reasons.

(i) Condensates contaminated with juice can not be used as 'make up' water for boiler feed.
damage to vapour pipes and calandria.

(iii) entrained syrup from last body will be irretrievably lost and will spoil the spray pond water.

Some types of save alls are shown in Fig. 7. The main types can be described in brief as under—

(i) In the helmet type catch all the vapour flow is reversed whereby the entrained liquid droplets impinge against the inside of the save all and drop down at the bottom for being drained out into the body; thus reversal of flow direction coupled with abrasion against the walls bring about recovery of liquid from vapour.

(ii) In the umbrella type separator the rising vapours hit the curved surface of the umbrella and are deflected downwards. This change in the vapour velocity together with turn of direction brings about separation of liquid from vapour.

(iii) In the centrifugal type catchall the vapours entering at the bottom are ejected tangentially through the vanes. The abrasion of vapour in the impeller coupled with centrifugal action brings about efficient separation of liquid from vapour.

(iv) Wiremesh separator—Layers of wiremesh netting forming a mattress of 10-15 cms thickness supported on grill, and firmly held to it arrest the juice droplets. The liquid droplets impinge on the netting as the vapour direction undergoes multiple changes. In some Indian factories the wiremesh separator have been found very effective in the first body or pre-evaporator. The wirenetting gets blocked after sometime and needs to be cleaned once in a month or so.

(v) Corrugated baffles—This new type arrester consisting of two layers of Louvres installed in the vapour space of evaporator, was developed in Australia by Frew. There are essentially two layers of corrugated plates inclined with an angle of 110° between the layers. The droplets carried by vapour impinge on the inclined surfaces of baffles and are thrown down the inclined surface and coalesce to form large droplets. The change of direction of vapour brings about collection of droplets at the intersection of lower and upper corrugated plates.

The above savealls are installed in the vapour space or dome of the body but in addition to these, entrainment separators consisting of different types of baffle arrangements are placed in the vapour pipe particularly for the last body of the evaporator. Usually a vertical cylinder with diameter bigger than that of the vapour pipe is installed in the vapour passage from last body of the evaporator to condenser. Baffles are fitted in the cylinder and syrup drained out from inclined or conical bottom of this separator.

7. DESIGN ASPECTS

(i) Heating surface according to French manufactures is the interior surface of the tubes i.e. the inner circumference of the tube multiplied by length of each of tube and the number of tubes in the calandria. The logic behind this method is that it is more important to calculate the area in contact with the juice to be heated, as the limiting
factor for heating is the heat transmission from tube to the juice. However, the American and British practice is to calculate heating surface taking into account the external surface of the tube in contact with vapour or steam i.e. the heating medium. These two methods of calculation give rise to a difference in heating surface. Yet another method could be to take mean of both exterior and interior surfaces in contact with heating fluid and juice respectively, as per practice followed in India.

7.2. Heat transfer coefficient—Evaporation coefficient is the weight of the vapour generated per square meter area of heating surface per hour (Kg/m²/hr). Specific evaporation coefficient is the amount of vapour produced per unit area of heating surface per hour per degree difference of temperature of heating medium and juice and is expressed as kg/m²/hr/°C. Hugot\(^5\) gives following figures of heat transfer coefficient for vapours furnished for different bodies of multiple effect evaporator adopted for design purposes by some manufacturers.

<table>
<thead>
<tr>
<th>TABLE</th>
<th>KCal/m²/hr/°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Triple effect</strong></td>
</tr>
<tr>
<td>1st vessel</td>
<td>2000-2500</td>
</tr>
<tr>
<td>2nd vessel</td>
<td>1500-1875</td>
</tr>
<tr>
<td>3rd vessel</td>
<td>750-1000</td>
</tr>
<tr>
<td>4th vessel</td>
<td></td>
</tr>
<tr>
<td>5th vessel</td>
<td></td>
</tr>
</tbody>
</table>

For pre-evaporator heated by steam of 2.5-3 kg/cm\(^2\) and with pressure in body of 0.5 kg/cm\(^2\) the heat transfer coefficient is 3,000 KCal/m²/hr/°C. These values are based on apparent temperature drop and are termed apparent heat transfer coefficients. The real coefficient of heat transfer can be arrived by taking into account the brix of juice in the vessel as also temperature of juice in the vessel which can be arrived at by adding B.P.R. due to brix and hydrostatic head.

7.2. Dessin formula takes into account all the above mentioned factors and can be applied to calculate evaporation coefficient of any vessel of an evaporator.

\[
C = 0.001 \times (100 - B)(T - 54) \text{ m units} \quad c = (100-B)(T-130)/16000 \text{ Br. units.}
\]

where

\[
\begin{align*}
C &= \text{specific evaporation coefficient in Kg/m}^2/\text{hr/°C or Ibs/ft}^2/\text{hr/°F. The temperature difference being real temperature drop} \\
B &= \text{brix of juice in the vessel} \\
T &= \text{Temperature of heating medium in the calandria in °C or °F}
\end{align*}
\]
For design purposes it is desirable according to Hugot to replace figure of 16000 by 20,000 in the formula in British units.

For pre-evaporator evaporation coefficient per \( \text{m}^2 \text{ per hr. in kg.} \) is around 40.

7.3. Evaporation coefficient i.e. the weight of vapour released per unit area per hour for different system of multiple effect evaporator are as under:

<table>
<thead>
<tr>
<th></th>
<th>Metric system</th>
<th>Br. system lb/sqft./hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single effect</td>
<td>98.0</td>
<td>20</td>
</tr>
<tr>
<td>Double effect</td>
<td>49</td>
<td>10</td>
</tr>
<tr>
<td>Triple</td>
<td>34</td>
<td>7</td>
</tr>
<tr>
<td>Quadruple</td>
<td>24.5</td>
<td>5</td>
</tr>
<tr>
<td>Quintuple</td>
<td>17.6</td>
<td>4</td>
</tr>
</tbody>
</table>

These are conservative values and in actual practice can be higher by 50%, but they are useful for design calculations.

8. SIZES OF VAPOUR PIPES

Vapour pipe sizes of different bodies are calculated according to following method—

(i) Vapour released from each vessel has to form basis of these calculations and the amount of maximum vapour should be found out and 10% of it should be added for safety purposes.

(ii) Referring to the steam tables find out specific weight of vapour at the actual temperature. Volume of vapour per second can be thus estimated.

(iii) Table on next page gives vapour velocities per second to be taken for these calculations. From the volume of vapour per second and vapour velocity, cross section of the pipe can be found out as below—

If \( x \) = weight of maximum vapour per second +10%  
\( Y \) = specific weight of vapour at the prevailing temperature  
\( m \) = volume of vapour per second  
\( V \) = Velocity of vapour per second.

\[ x \times Y = m \]

\[ m + V = n \text{ area of pipe} \]

Or \( 4n/\pi = D^2 \), the diameter of pipe is \( D \).
The table shows that vapour velocities progressively increase from first to last bodies. Maximum permissible velocity from last body is 75 m/second.

Vapour velocities m/sec.

<table>
<thead>
<tr>
<th></th>
<th>Triple</th>
<th>Quadruple</th>
<th>Quintuple</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Exhaust to 1st body</td>
<td>25-30</td>
<td>25-30</td>
<td>25-30</td>
</tr>
<tr>
<td>2. Vapour from 1st body</td>
<td>30-35</td>
<td>30-35</td>
<td>30-35</td>
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<tr>
<td>3. Vapour from 2nd body</td>
<td>40-45</td>
<td>35-40</td>
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<td>4. Vapour from 3rd body</td>
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<td>5. Vapour from 4th body</td>
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<tr>
<td>6. Vapour from 5th body</td>
<td></td>
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<td>50-60</td>
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</table>

9. CONDENSATE REMOVAL

9.1. In the calandrias the heating vapour parts with its latent heat and is converted into liquid condensate which must be removed without allowing any accumulation. The condensate outlet pipes are connected to lower side of the calandria tube plate and care has to be taken to locate them properly, their placement being arranged so as to provide one outlet for each 2.8 m² of the area of the calandria. The drain pipes of a body should be sized on the basis of flow rate of 0.6 m/sec. and if they are connected to common pipe the velocity should be taken as 0.75 m/sec.

9.2. Condensate flash—The temperatures of condensates from first body to last body go on decreasing and if a high temperature condensate from one vessel is passed to the succeeding calandria, which is at a lower pressure a spontaneous evaporation will result, the amount of water evaporated depending on the heat which the condensate will part with. Thus this extra vapour generated due to flash effect will add to the vapour available for boiling and if in this way condensate from each vessel is circulated from one calandria to the next, in the entire set of bodies the net gain in evaporation in the last body of a quadruple effect without vapour bleeding is 11.2% and for the entire quadruple 4.6%. As against the gain in evaporation rate, there are certain disadvantages attendant with adoption of this system viz.

(i) As condensate temperature is reduced, wherever hot condensates are used as in boiler feed water tank additional heat energy will have to be spent at that station.

(ii) In the event of contamination of condensates from any calandria due to entrainment the entire condensate will be spoiled. In view of the above, the prudent way would be to separately pump the first and second body condensates.
10. JUICE PREHEATING

The clear juice entering the evaporator first body is usually at lower temperature than that prevailing in the body and usually this difference can be 8° - 10°C if the juice is passed from the settler into the evaporator. The first vessel has thus to heat the incoming juice to the temperature of boiling juice which involves some heating surface for heating alone. This additional heating surface to be provided for supplementing the heating surface required for evaporation is equivalent to—

\[ S = 0.6Q (t_1 - t_2) \text{ in Br. Units} \]

Or

\[ S = 0.1022Q (t_1 - t_2) \text{ in metric Units} \]

where:

\( t_1 \) & \( t_2 \) are the temperatures of boiling juice and juice entering respectively.

The evaporation taking place in the first body of a multiple effect is very important in view of its impact on the function of the evaporator set, in so far as total evaporation in subsequent bodies is concerned. It follows therefore that maximum heating surface can be made effective use of only by feeding the clear juice at temperature of boiling juice in the first body. If the juice is overheated to a temperature somewhat higher than that of boiling juice, extra evaporation can be obtained by flash effect.

In modern plants the clear juice heater precedes the preevaporator or first body of evaporator. Plate type heater is now-a-days widely used for clear juice heating in modern sugar plants. This heat exchanger consists of a number of stainless steel corrugated sheets mounted on adjustable frame. Flow is arranged in ports provided at corners. Plate heat exchangers have very high heat transfer rate on account of thin film of liquid in each pass and it is reported that the value of heat transfer coefficient is three times in a plate heat exchanger as compared to tubular heater on water.

11. PRE-EVAPORATOR

11.1. Preevaporator or vapour cell during boiling of clear juice generates vapours which are used for either juice heating or pan boiling. Thus the place of preevaporator in the entire scheme of steam economy is unique and the design or planning for its installation is guided by following consideration.

(i) The clear juice to be fed to vapour cell has to be heated to the temperature above that to be maintained in vapour cell.

(ii) The vapours to be supplied to pans have to be of 0.2 to 0.4 kg/cm\(^2\) pressure and the exhaust steam supply to vapour cell calandria has to be of about 0.7 kg/cm\(^2\).

(iii) The juice retention in the preevaporator has to be as short as possible to avoid sucrose inversion and loss of reducing sugars.
(iv) Steady and regulated feed is essential so as to ensure constant supply of vapour to pans or juice heater.

It therefore follows that the preevaporator has to be operated to full capacity not only for supply of vapour but, also to maintain minimum retention time for juice at high temperature and proper selection of design has to take account

(i) high velocity of juice

(ii) high rate of heat transfer

(iii) ample vapour space.

Besides the tubular evaporator body design met with the multiple effect, with sealed down take or annular or multiple downtake, few climbing film and falling film evaporator designs have been introduced in cane sugar industry in recent years.

11.2. Kestner evaporator—Based on the concept of 'Climbing film' this evaporator is designed on the principle that when the juice is heated in long vertical tubes, the vapour bubbles formed in lower parts of tubes rise along the surface of tubes, increasing in size as they move upwards. The upper portion of the tubes is full of ascending bubbles followed by film of juice. This brings about high rate of heat transmission and high rate of evaporation per unit area of heating surface due to—

(a) high velocity of juice and

(b) very small distance between the surface of juice particles and the tube surface.

In operation the juice level in the Kestner is always low corresponding to one fifth of the height of the tube which in effect means very low hydrostatic head. The juice feed is arranged through a preheater so as to maintain temperature of incoming juice 5°C higher than that of the boiling juice in the preevaporator.

The tubes in the Kestner evaporator are of 7 m length and about 25-37 mm dia. A vapour separator is located either at the top or on the rear side. As the juice travels through the tubes within half a minute the risk of sucrose inversion or colour formation is minimised though the pressure of steam is high and juice temperature is also high. Due to high juice velocity and low juice retention the scale formation on the heating surface is negligible which contributes to high heat transfer rate. A buffer storage tank for clear juice should be installed to maintain constant feed. The Kestner rising film evaporators have been in operation in beet sugar industry since long.

11.3. Semi Kestner—The semi Kestner evaporator used mainly as vapour cell for supplying vapour to pans consists of two main parts viz. calandria without downtake and the juice vapour separator on top of it. This design of evaporator characterised by 4 m long tubes is considered more suitable for cane sugar mills, as compared to Kestner evaporators, and semi Kestner preevaporators have been installed in a number of sugar mills in India. The vapour space is located on top of the calandria and impeller type separator mounted over the top tube plate of the calandria helps separate entrained juice from vapour. Juice entry is from bottom and thick juice exit is arranged from side above the top tube plate. This is a single pass evaporator and hence has no downtake like the Kestner. The clear juice is
pumped under constant pressure at the bottom and owing to the high velocity of juice through long and narrow tubes, thin film of liquid along the surface is formed and the bubbles formed expand during the upward flow, dragging liquid up the tube. Thus the mixture of vapour and thickened juice is carried upwards and from this emerging mixture the liquid is separated by the special separating device provided above the top tube plate of the calandria.

The operation of the vertical rising film evaporator bodies which are suitable only for thin juices needs some special precautions such as proper control on

(i) pressure of steam

(ii) juice feed flow and

(iii) clear juice pH for obtaining satisfactory results.

The steam pressure in calandria has to be 0.7-1 kg/cm$^2$ since the rate of evaporation is determined by the temperature difference between steam and boiling juice. Water connection is provided in the body to be utilised only when the juice feed is interrupted. Since the tube length in semi Kestener is twice that in the 'Roberts' body commonly used in multiple effect evaporators the juice velocity is very high and consequently due to high heat transfer rate the heating surface employed is considerably reduced-nearly halved in this rising film vertical tube evaporator with reduction in the juice residence time. According to Perk the juice residence time in semi Kestner is 1/4 to 1/3 of that in Roberts body of the same evaporation capacity.$^{10}$

11.4. Falling film type evaporator

11.4.1 Falling film type evaporators are of two types

(i) Horizontal type and

(ii) Vertical tube type.

In the Lillie horizontal evaporator$^{11}$ a bank of slightly sloping tubes is mounted in a tube plate. The tubes are closed at one end and open to steam chest from which steam passes into the tubes. The condensate flows out into the steam chest. Liquid is pumped into distributor head above the tubes, passed through the bank into a reservoir and recirculated, a part of it being sent out. With thin film of descending liquid the heat transfer rate is very high. The vapour separates from the liquid in the space around the tubes and an entrainment catcher is installed in the vapour outlet.

11.4.2 In the vertical tube falling film evaporator of Buckau Wolf design$^{12}$ the tubes are 8-10 m long expanded in tube plates. The juice is fed through a bent tube to a distributor which consists of V and U shaped channels with toothed overflow edges, arranged in such a way as to achieve uniform distribution of juice and wetting of tubes. The steam inlet is near the top of the heating chamber while the condensate is drained out at three points at the end of the Calandria.

The vapour and the liquid flow down the tubes into the wide vapour space where the thick liquid separates from the vapour and is drawn off through a pipe connection at the
lowest point while the vapour outlet is located at the upper sloping portion of vapour belt. This evaporator design is characterised by very low residence of juice and hence is supposed to cause least decomposition of juice constituents.

In all the falling film vertical tube evaporator designs the main common points are

(i) Juice feed at the top through distributor

(ii) tube length of 8-10m.

(iii) descending film of juice and vapour into vapour space below

(iv) withdrawal of thick juice from bottom of vapour space.

As there is no hydrostatic head with its effect on boiling point elevation, and the juice passes in thin film through the tubes carrying with it the vapour the heat transfer rate is very high. In view of the importance of uniform distribution of juice in all the tubes of the upper tube plate special attention is paid on the juice distribution devices in different designs. The distribution of juice or wetting of tubes is calculated as \( m = \frac{Q}{nD} \) where \( m \) stands for wetting of tubes, \( Q = \) weight of juice in kg/hr. \( n = \) number of tubes and \( D = \) diameter of tube. The optimum value is considered to vary from 500-600 to 1200-1500 kg/hr/m\(^3\).

In Fives Cail—Babcock F.F. vertical tube evaporator the tubes are of stainless steel and of 45.1 x 48.3 mm size opening. The area of tube plate is divided into sections and juice is fed to each section through distributors. Each distributor transfers juice on conical deflectors of decreasing diameter, with hole in the centre. The juice drops on the rows of parallel bars mounted above a row of tubes and as final row of bars is above the tube plate, the juice is delivered to the tube plate in the inter row space and prevented from falling into the tubes by special caps located over each tube. The juice this way enters only along the periphery of tubes.

There is no recycling arrangement for juice in the F.C.B. design, and three juice outlet connections are provided at the base while the vapour passes through an entrainment catcher before leaving the exit opening in the upper part of vapour space.

The falling film evaporators have higher heat transfer rate than rising film type and they can be operated with steam at 135°C or 2.1 kg/cm\(^2\) pressure. F.F. evaporators have gained acceptance in beet sugar industry and may be tried out in cane sugar industry in the interest of energy saving. In the white sugar process of manufacture, the use of thin film evaporator would be restricted to pre-evaporator and conditions of operation have to be so adjusted as to prevent

(i) inversion of sucrose

(ii) destruction of reducing sugar and

(iii) colour formation in boiling.

As stated earlier both rising film type and descending film type evaporation is a sensitive operation and cannot tolerate fluctuations in juice flow or steam supply which would result in unsatisfactory performance and higher losses in manufacture.
12. DOUBLE EFFECT EVAPORATOR

Double effect evaporator is installed in some factories for furnishing vapour for the entire pan boiling operation. This effect consists of rising film type semi Kestner first vessel coupled to an ordinary Robert type body as the second effect. The semi Kestner supplies vapours of about 0.4 to 0.5 kg/cm² pressure to final masscuite boiling and to second body the vapours from which are used for remaining pans. The vapours from the second body are at about 0.1 kg/cm². Steam pressure in the calandria of semi Kestner is 0.8 - 1 kg/cm² while the second body calandria receives vapour of 0.4 - 0.5 kg/cm² pressure. The corresponding temperatures in calandria are 120° - 140°C and 105° - 110°C, while the juice temperature in the semi Kestner is 110° - 115°C.

A clear juice preheater for heating clear juice to 110° - 115°C i.e. the temperature of boiling juice in Semikestner as also a buffer storage tank for maintaining stable feed are essential for efficient operation of this pre-evaporator.

Conflicting reports have been published regarding the effects of high temperature boiling in two bodies on the sucrose inversion and colour formation. It is possible that fluctuations in vapour demand from pans affect the working of both the bodies of pre-evaporator. Secondly whenever the pH of juice at the boiling temperature is lower than 7.0 inversion is bound to be accelerated. Perhaps more experience with the operation of this system will throw fresh light on the decomposition of sugars under rigid control of juice pH and flow rate of juice as also the temperature and pressure of exhaust steam applied to the semi Kestner.

13. CIRCULATORS

A circulator in the present context is a small evaporator body situated near the particular body of a multiple effect evaporator, whose capacity it is expected to augment. Sometimes during plant expansion or rationalisation it is found that a particular body of evaporator set is short of capacity and under such circumstances replacing the set or body may prove costly and impracticable when an auxiliary vessel can be installed to operate in conjunction with that body. These units are inter-connected on the juice side by pipes below and above the tube plates. The upper tube plate of the circulator is at the same level as that of evaporator vessel connected to it. Usually these circulators are used for last vessel of multiple effect but the vapours to their calandria are taken from first or 2nd vessel. Thus if a circulator is connected to a fourth body of evaporator and heated by vapour from first vessel, the juice circulation will be very vigorous with improved rate of evaporation since the juice in circulator will, thanks to larger temperature gradient, boil vigorously and will be circulated through the main body rapidly.

Circulator installation is not good from the steam economy angle for the simple reason that vapours from earlier vessel-1st or 2nd body are effectively used in evaporation only once or for less number of times than in the normal design of multiple effect set. It is thus useful only for augmenting the capacity of last body or last but one body of evaporator set, as a short term arrangement and will have no place in new installations or in long term planning of sugar plant.
14. THERMO COMPRESSOR

When the exhaust steam produced by the prime movers of mills and turboalternator falls short of the requirement of evaporator, pans and juice heaters in boiling house, live steam from boiler at high pressure is mixed with the exhaust steam after passing it through reducing valve for reducing its pressure. Thermocompressor is a device which boosts part of the vapour from a boiling vessel by mixing high pressure steam with the vapour, so that the resulting mixture of vapour and live steam is used again in the heating chamber of the vessel for boiling. In this apparatus live steam enters near the top and aspirates vapour, the compressed mixture being discharged from bottom. The high pressure steam passes through a nozzle and its potential energy is converted into kinetic energy and it carries the low pressure vapour with it. There are thermo compressors with more adjustable live steam nozzles. The thermocompressor involves no moving parts or external power supply and requires very little maintenance. The use of thermocompressor must be carefully planned and the system design has to take into account the complete operation of the vessel to which it is going to be attached, the pressures and quantities of vapours and live steam to be employed. In cane sugar industry this system can be installed for pre-evaporator or first vessel of multiple effect evaporator.

If one kg. of high pressure steam compresses 2 kg. of vapour the total vapour fed would be three kgs. which would evaporate three kgs of vapour from juice out of which two kgs. will be aspirated by thermocompressor and one kg. vapour will either go to other units as in the case of pre-evaporator or to 2nd body calandria in a multiple effect evaporator. The incondensible gases from evaporator working in conjunction with thermocompressor are let into the vapour space of the same or into the vapour pipe joining the calandria of the next body of the multiple effect.

The entrainment ratio \( \mu \) indicates the ratio of vapour aspirated to the high pressure steam.

\[
\mu = \frac{\text{Wt of vapour aspirated}}{\text{Wt of actuating steam}}
\]

Entrainment ratios for conditions which have relevance to pressures of vapour, exhaust and live steam normally obtained in Indian plants are presented in Table 4.

The degree of superheat has marked influence on the specific volume of vapour and volume changes occur more as the vapour to be compressed approaches 100°C. Thus the temperature of vapour aspirated is very crucial for selection of proper thermocompressor.

Effect on steam consumption—Assuming no vapour bleeding and thermocompressor attached to first body of quadruple the steam saving due to thermocompressor

\[
\text{will be } \frac{\mu}{n} \times ^1 x
\]

\( x = \) live steam

\( \mu = \) entrainment ratio
\[ n = \text{number of effect} \]
\[ \text{Steam saving} = \frac{\mu}{n} \times 1 \]

Output regulation—By providing 3-4 nozzles for the actuating live steam the thermocompressor output can be regulated as per the requirement of the vessel to which it is attached. The nozzles are opened and their regulation takes care of variations in the exhaust steam supply but it is essential that their operation is controlled automatically. This automatic control, of nozzles imparts flexibility to the system and helps in efficient operation.

The thermocompressor is a useful but delicate apparatus and can give the desired steam economy in cane sugar mill under following conditions—

(i) The exhaust production of prime movers must necessarily be 15-20% short of steam requirement of the process.

(ii) The live steam feed to the thermocompressor is regulated to suit the variations in exhaust due to pan operation.

(iii) The apparatus is designed taking into account the correct temperature and pressure of vapour to be compressed.

15. VAPOUR RECOMPRESSION

Low pressure vapours with high latent heat from pans or evaporator can be compressed by positive displacement axial flow, centrifugal type compressor driven by turbine or electric motor. It can be installed for preconcentrating clear juice prior to feeding the multiple effect evaporator which will substantially reduce steam load at this station and allow minimum vapour to go to condenser. In essence a turbo compressor will convert low pressure vapour into high pressure at the expense of mechanical energy. The most suitable conditions for use of this equipment are—

(i) Mills with high pressure boilers and turbines operating at 30-40 kg/cm\(^2\) where the exhaust production is low.

(ii) Sugar mills with distilleries attached, which receive their exhaust steam from sugar mill boilers.

According to Chen\(^{16}\) for compression ratio of 1.8 theoretical input of isentropic energy of 45 B.ThU/Lb (25 Kcal/kg) results in recovery of 950 B Th U/lb (544.4 Kcal/Kg) when compressing steam from 5 lbs/\(\text{sq} \text{in}\) to 20 lbs/\(\text{sq} \text{in}\) (0.35 kg/cm\(^2\) to 1.4 kg/cm\(^2\)).

Compared to thermocompressor which is a simple device requiring practically no maintenance, turbo compressor is an expensive piece of equipment which calls for high electric or mechanical power and good amount of care. Nevertheless as it can recompress low pressure vapour for reuse in process it holds important place in the overall scheme of energy conservation.
REFERENCES

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2. Ibid.
5. E. Hugot 'Handbook of Cane Sugar Engineering' Ed. 3 1986 p. 572.
8. Ibid p. 584.
10. C.G. M. Perk 'Manufacture of Sugar from Sugar Cane' 1973 p. 81.
12. Technical literature of Manufacturers.
## TABLE 1
RELATION BETWEEN PRESSURE AND TEMPERATURE OF DRY SATURATED WATER VAPOUR AT PRESSURES BELOW ATMOSPHERIC (METRIC UNITS)

<table>
<thead>
<tr>
<th>Vacuum (cm)</th>
<th>Hg. abs. (cm)</th>
<th>Abs. press. (kg/cm²)</th>
<th>Temp. (°C)</th>
<th>Vacuum (cm)</th>
<th>Hg. abs. (cm)</th>
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<th>Temp. (°C)</th>
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<td>0.0000</td>
<td>11.2</td>
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(From Handbook of Cane Sugar Engineering by E. Hugot and G.H. Jenkins Ed II 1972 p. 489.)
TABLE 2

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(°C) AT 760 MM PRESSURE. (AFTER CLASSEN AND THEME)

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(From Handbook of Cane Sugar Engineering by E. Hugot and G.H. Jenkins Ed II 1972 p. 491)
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TABLE 3

**BOILING POINT ELEVATION** $e'$ **AT THE BOTTOM OF A LIQUID COLUMN.**

**RELATIVE TO BOILING POINT AT THE SURFACE** $T$ **(IN °C)**
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<th>100 e'</th>
<th>90 e'</th>
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(From Handbook of Cane Sugar Engineering by E. Hugot and G.H. Jenkins ed II 1972 p. 494)
TABLE 4

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P = absolute pressure of actuating live steam in Kg/cm²

(Handbook of Cane Sugar Engineering by Hugot & Jenkins III Ed. 1986)
1. The main function of the evaporator station is to concentrate clear juice containing around 83-86% water, and transform it into syrup containing 35-40% water with minimum expenditure of steam without bringing about any change in the composition of dissolved constituents, which would affect adversely the recoverable sugar at the crystallisation stage. At the time of commencement of this operation the condenser water is started and vacuum developed in the last body connected to a condenser. This is followed by juice feed and opening of exhaust steam valve, which leads to boiling and vapour flow. Incondensible gas valves are opened and condensate of the vapour from each calandria removed by means of pumps. As the juice passes from first body to second and so on on the vapours from boiling liquid flow through one vessel to the calandria of succeeding one. Vapours from last body are condensed in the condenser connected to the vapour space of the same through a vapour pipe. Once the flow of clear juice is stabilised and concentrated syrup of about 60°-65° Bx. leaves the last body continuously the operator has only to check the temperatures, vacuum or pressure at each body along with exhaust steam pressure. After smooth operation is established there will be very little variations in the pressures and temperatures of bodies so long as flow of juice, steam supply and vacuum show no fluctuations.

2. HEAT TRANSFER
2.1. Evaporation or heating in any process operation like juice heating, pan boiling or juice concentration depends on the rate at which the heat is transferred from the hot condensing steam or vapour to the cooler liquid through the tube walls. Thus in an evaporator evaporation will be rapid when the heat transmission rate is high. Heat transfers thus takes place according to the equation:

\[ Q = UA \ t \]

where:  
\( Q \) = Quantity of heat transferred  
\( U \) = Overall heat transfer coefficient  
\( A \) = area of heat exchange in \( m^2 \)  
\( t \) = difference in temperatures of heating steam or vapour and boiling liquid in°C

The coefficient \( U \) depends on three resistances to heat transfer. 
(i) steam side resistance from heating fluid to tube surface \( RS \).  
(ii) tube wall resistance \( RW \)  
(iii) liquid side resistance i.e. from surface to cold liquid \( RL \).
This can be expressed in the equation—

\[ U = \frac{1}{\frac{1}{RS} + \frac{1}{RW} + \frac{1}{RL}} \]

Factors which adversely affect the heat transfer coefficient are as under—

(i) Steam or vapour side—
   (a) Incondensible gases,
   (b) high degree of superheat
   (c) scale
   (d) condensate

(ii) liquid side:
   (a) scale
   (b) hydrostatic head
   (c) viscosity
   (d) B.P.R.
   (e) surface tension.

Similarly heat transfer increases due to—

(a) steam or vapour temperature
(b) velocity of liquid
(c) temperature difference

2.2. Mechanism of heat transfer and boiling—In a multiple effect evaporator, the temperatures in the first body are about 100° - 105°C and in the last body around 56°C, as the pressures are reduced gradually. The heat transfer from steam or vapour in the steam chest to the boiling liquid in contact with the heating surface is effected in the following ways—

(i) Latent heat of the vapour is transferred to the solid surface of tubes,

(ii) Heat flows through the metal surface to the liquid in contact with inside surface of the tubes.

(iii) Heat is transmitted to the entire mass of boiling juice.

In connection with the overall heat-transfer in the evaporator the undermentioned factors have, significant bearing on the boiling performance:

(a) In evaporator brass tubes are commonly used in the calandria. Taking the
Heat conductivity of copper which is known to be very good conductor of heat, as unity
the conductivity of heat through various materials would be as under—

(i) Aluminium  \[ \rightarrow 0.546 \]
This shows the importance of extraction of water and gases from the steam chest as also the part played by scale in impeding the heat transfer from heating medium to boiling liquid.

(b) The latent heat of steam or vapours provides heat for boiling and on transfer of heat the vapour gets condensed into water. This condensate should not accumulate in the heating chamber but should be drained out quickly. Along with removal of water the gases contained in the vapour commonly known as incondensible gases have to be vented out in view of the resistance offered by them to heat transfer.

(c) As far as the metallic resistance is concerned, the normal practice is to use brass tubes, which conduct heat very well. In some plants aluminium tubes, mild steel or stainless steel tubes have been fitted in the evaporator calandrias. However compared to the resistance offered by gases or water or scale, the resistance of these metals to heat flow is extremely low. Nevertheless brass tubes are preferred to other types from the point of view of heat transfer rate, durability, resistance to corrosion and suitability for chemical treatment at the time of descaling.

(d) On the juice side the formidable barrier to heat transfer would be the scale deposited on the inside of the tubes. Over length of time, scale builds up on the heating surface and unlike water or gas accumulation which can be relieved within a short time the scale removal is a time consuming procedure followed once in 2-3 weeks.

(e) As a result of transfer of heat from the vapour to the juice, it reaches the boiling temperature, and bubbles are formed, which being lighter than the liquid rise to the top. As density of juice increases so also the viscosity, which affects the circulation, the net result is the lower heat transfer rate from first vessel to the last vessel.

2.2. Evaporator operation is essentially concentration of juice to syrupy state and envisages no changes in composition of juice. The operating parameters with respect to steam pressure and juice level in bodies and final vacuum have to be maintained such that—

(a) no inversion of sucrose occurs

(b) reducing sugars are not decomposed

(c) juice is not lost in vapours either to any of the calandrias or to condenser.

Thus the control of operation for this purpose will require that—

(i) juice flow is maintained free from wide fluctuations,

(ii) steam pressure is constant
(iii) Vacuum in the last body does not exceed 625 - 650 mm. and is steady
(iv) Juice levels in different bodies of quadruple are about 35-40% in I vessel, 25% in II vessel and 20% in last two bodies of a quadruple.

It is important that juice remains in contact with heating surface at high temperature for minimum time for avoiding decomposition of sugars. In a properly designed evaporator this can be achieved by regulating flow of juice, maintaining optimum levels and controlling steam supply. If the juice levels are lower or higher than optimum the circulation is affected and consequently the rate of evaporation is lowered and chances of entrainment increase.

3. INCONDENSIBLE GASES

3.1. Removal of incondensible gases many times referred to as ammonia gas during running of evaporator is essential as their accumulation brings down the heat transfer rate. The control of incondensible gas extraction is effected by regulating a valve outside the evaporator body, in the pipeline which connects the incondensible gas extraction pipes of the calandria to vapour space of the same body or to a common pipe connected to the condenser. If the valve is fully open lot of useful vapour will be carried away along with gases while if the passage is too much restricted gas accumulation will take place. According to Honig nearly 50 times more vapour by volume has to be let out along with incondensible gases for normal operations of evaporator.\(^1\) A rough guide provided for regulating the ammonia valves is to measure temperatures of vapour entering the calandria and the gas in the ammonia line before the valve. This difference is 1° to 2°C, the temperature before the valve being always lower. In the exhaust steam fed to an evaporator the incondensible gas content is low but it goes on increasing from second vessel to last vessel, and therefore the gas valve opening has to be increased from first to last body progressively. Thus the judicious setting of gas valves has a great bearing on the performance of multiple effect evaporator.

3.2. The source of the incondensible gases can be air-leaks in the system as also the gases evolved during concentration on account of chemical reactions. With juices clarified by sulphitation the oxygen in the gases partially oxidises the sulphites to sulphates. The decomposition of organic non-sugars results in CO\(_2\) formation while nitrogenous compounds give rise to ammonia formation.\(^2\) The amides in cane juice like aspergine, glutamine decompose during the boiling with evolution of ammonia which forms part of incondensible gases and also gets dissolved in the condensates. The ammonia in the steam chest, if not vented out properly attacks the zinc component of the brass tubes causing wear and leaks. This wear has been observed in a number of factories where the top portions of the brass tubes just below the top tube plate were found to have undergone corrosion. At times it is noticed that a number of tubes in one pocket of the calandria are damaged due to ammoniacal corrosion, indicating the accumulation of ammonia on the vapour side in that area. This type of corrosion is found in the bodies heated by vapour particularly the latter bodies of the multiple effect. It is thus essential to provide proper venting connection for the incondensible gases and to operate the vents so as to prevent accumulation of ammonia.
4. CONDENSATES

4.1. For smooth operation of evaporator, extraction of condensates from the calandria of each body is as important as removal of syrup or passage of juice from first body to last body. In the event of any leakage developing in the tube the evaporation rate is depressed due to one of the two reasons: one if the leak is due to damage of the upper end of the tube, vapour from calandria will be drawn in the vapour space of the body and secondly if the tube rupture is at the lower end near the bottom tube plate, the condensate will be sucked in the body. This problem is sometimes encountered in working, more in the latter bodies of the multiple effect. Such leaks apart from disturbing the vacuum in the system and the evaporator operation can lead to heavy entrainment of juice boiling in the vessel with leaking tubes.

4.2. In modern plants condensates are extracted by connecting the condensate drain of body to the suction of a centrifugal pump. It is essential that during running, leakage of air into the system upto the pump discharge is prevented since it would obstruct the flow of condensate from the calandria. The pressure equalising pipe connecting the pump to the vapour chest takes care of the small leaks in the pump. Nevertheless large amount of air getting into the condensate pipes through flange joints or even pump glands has to be checked and stopped. To prevent the condensate pump running dry in many factories the delivery pipe of the pump is connected to suction pipe so as to ensure some liquid in the pump all the time. Smooth flow of condensates from body so as to prevent any accumulation in the steam chest is absolutely essential for proper functioning of evaporator.

4.3. The temperatures of condensates from different calandrias are less than those of vapours and roughly correspond to the temperatures calculated by following formula—

\[
\text{Temp. of condensate} = \text{temp. of vapour} - 0.4 \left[ \text{temp. of vapour} - \text{temp. of juice in the vessel} \right]
\]

Thus the condensate from first vessel will be around 95° - 100°C and as this is derived from condensed exhaust steam is sent to boiler feed tank. The condensate from second vessel is at about 90°C and is partially used to make up for the shortage of boiler feed water, the remaining being used in the process. The condensates from the last bodies are necessarily used only in boiling house, the surplus being stored in a separate tank after meeting the requirement of the process. The condensates should be tested often for presence of traces of sugar, as they can be contaminated with juice due to occasional entrainment.

4.4. Composition—The condensates are not pure water but contain volatile compounds of boiling juice, which are mostly organic non-sugars. The main impurities are ammonia, CO\(_2\) aldehydes and organic acids. Data relating to the composition of condensates of quadruple bodies at Yeshwant factory in Indian by D.P. Kulkami,\(^4\) from both sulphitation and defecation processes indicates that—

\((i)\) pH of condensates is found to vary from 7.5 to 9 in II to IV bodies of quadruple with both defecation and sulphitation treated juice.
Organic reducing matter as determined by KMnO₄ titration, goes on increasing from 2nd to 4th body condensate. There is no difference in organic matter in condensates from both processes.

Ammonia content of condensates generally varied from 8 to 40 ppm. while operating defecation and 7.5 to 30 ppm. from sulphitation process although sometimes lower ammonia content was also obtained.

In general ammonia content was higher in second body condensate than in the condensates from latter bodies.

The amides in cane juice like aspergine, glutamine decompose at high temperature to form ammonia and amino acid, which is distilled off and partly gets dissolved in condensate. Immature cane gives high ammonia in condensates, which gets reduced as cane reaches maturity.

4.5. Use of condensates—Total evaporator condensate from the vapours in a normal factory employing vapours from different bodies for juice heating is about 60-62% cane out of which around 48-50% is collected the remaining going to condenser. The condensates with temperatures varying from 60°C-98°C are used in the manufacturing process at different stations from mills and boiler to centrifugals as they are almost free from inorganic salts and are of very high purity. Conservation and proper use of these condensates assumes special importance both from the energy conservation angle and because of their widespread use throughout the process. The mode of use of these condensates in sugar mill can be represented approximately as in Table below—

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Station</th>
<th>Condensate % cane</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mill</td>
<td>20-28</td>
<td>Imbibition</td>
</tr>
<tr>
<td>2.</td>
<td>Boiler</td>
<td>5-7</td>
<td>Make up water for boiler feed</td>
</tr>
<tr>
<td>3.</td>
<td>Clarification</td>
<td>4-6</td>
<td>(i) Lime preparation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(ii) Washwater for filter</td>
</tr>
<tr>
<td>4.</td>
<td>Pans</td>
<td>5-6</td>
<td>(i) For molasses conditioning,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(ii) As movement water in pans</td>
</tr>
<tr>
<td>5.</td>
<td>Centrifugals</td>
<td>5-6</td>
<td>(i) As wash water in centrifugals</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(ii) For melting sugar</td>
</tr>
<tr>
<td>6.</td>
<td>Crystallisers and Miscellaneous</td>
<td>5-6</td>
<td>(i) Reheating cooled massecuites</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(ii) Floor washing etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>44-52</td>
<td></td>
</tr>
</tbody>
</table>
With elaborate vapour bleeding being practised in modern plants, the available condensate if properly preserved not only meets the requirements of the operations but some surplus is usually stored for being used after long mill stoppage. It is however necessary to avoid contamination of condensates with sugar bearing materials and carry out frequent tests for traces of sugar. This is particularly important for the condensate from second body which is used to supplement the condensed steam being used as boiler feed water.

5. CHANGES IN JUICE COMPOSITION

In the evaporator the changes in composition of juice are occasioned mainly under influence of heat and to some extent concentration. The chemical transformations taking place are mainly concerned with decomposition of sugars and supersaturation of salts.

(a) Inversion—Sucrose inversion is essentially a function of pH, temperature and time, pH of clear juice changes with temperature and as per findings of D.P. Kulkarni this drop in pH can be 0.3 to 0.4 in the case of sulphitation clarified juice, with temperature rise from 30°C to 90°C. Thus inversion is bound to occur when residence time at temperatures from 100° - 105°C exceeds a certain limit as reported by D.P. Kulkarni and M.K. Patil. The time and temperature limits of maintaining sucrose undecomposed have to be determined by each factory as the juice composition which varies from factory to factory and in different periods exerts profound influence on the inversion reaction. In pre-evaporators which supply vapours to pans this factor of inversion assumes special significance in view of high temperatures of boiling adopted in these bodies.

(b) Effect on Reducing Sugars—Reducing sugars and particularly the fructose are sensitive to heat, the latter getting destroyed with heat resulting in apparent purity rise of juice. In evaporator, transformation of reducing sugars at high temperatures gives rise to different products and one of them is methyl glyoxal which being volatile finds its way into condensates. Yet another reaction is the formation of colour precursors from reducing sugars and amino acids. These colourless compounds formed in evaporator produce coloured nonsugars at crystallisation stage. The reducing sugar transformation in the evaporator is more pronounced with juices which have been subjected to high pH during clarification, and in carbonation factories this decomposition of reducing sugars is high, the extent of destruction depending on the temperature and time of retention at high temperature. One way to control the transformation of reducing sugars is addition of phosphoric acid to clear juice which brings down the reactivity of reducing sugars particularly the fructose. After Gupta and Ramaiah advocated this phosphate addition to clear juice many factories in India have been practising this procedure. However the amount of phosphoric acid to be added should be carefully determined by studying the drop in pH together with sucrose inversion aspects.

(c) Effect on colour—Colour development in plantation white sugar manufacture by sulphitation, in the evaporator is much low or negligible so long as the retention of
juice at high temperature is short in the preevaporator or first body of multiple effect. The data collected in Java with colour formation in carbonation factories showed increase of up to 15% colour development while in India with sulphitation clarified juices the increase in colour was 0.477% which is negligible in the first effect of evaporator. If the temperature of boiling is high the juice retention should necessarily be low for preventing increase in colour. The colour formation in evaporator is mainly due to iron content in the thin juice, and colour development in sulphitation clarified juice is much lower than that in defecation juices due to the depressing effect of sulphites on colour formation in the former. According to Honig the transformation and decomposition occurring at high temperatures or high retention time result in formation of precursors which produce colour in the later crystallisation process.

Investigations relating to the development of colour in Beet sugar industry in the evaporator, reported by Stanislaw Zagrodzki point to the importance of maintaining low levels of juice in the vessels. The increase in colour would be 50-60% with reasonably low juice levels but if the juice levels are high the colour may increase up to three-times according to their findings. The abnormal increase in colour with high juice levels is attributed to both—

(a) high retention time and

(b) increase in the boiling temperatures of juice in the lower portions of juice on account of higher hydrostatic head.

Although the conditions of cane juice with regard to composition, pH and system of boiling are different from those obtaining in beet juice processing the principle of maintaining low levels in evaporator for preventing decomposition of sugars and development of colour particularly in the preevaporator and first body of the evaporator is equally applicable to cane sugar industry. It is thus important that both for preventing colour formation in the juice concentration or in crystallisation of sugar the time of contact of juice with heat is minimum and a proper balance of high temperature of juice and retention time at high temperature is maintained for preventing colour forming reactions.

(d) Organic non-sugars—The amides of amino acids which are unstable at high temperature decompose to form ammonia which is released on distillation of juice and is found in condensates. The ammonia formed in clarification is distilled off in the evaporator. The amino acids combine with hexoses during evaporation process and the completion of this reaction takes place in the pan station. Some weak organic acids and higher fatty acids are distilled off with vapour and are found to some extent in the scale deposited on the heating surface.

(e) Suspended impurities—The clear juice from clarifier does contain suspended impurities but more suspended matter is generated during evaporation on account of precipitation of salts contained in the juice which have exceeded their solubility. The studies by D.P. Kulkarni have shown nearly five-fold increase in suspended matter from clear juice to syrup stage in a quadruple in the case of juices clarified by
The suspended impurities go on increasing at each stage of crystallisation and are very high in 'A' heavy and 'B' heavy molasses. The analysis of the suspended impurities separated from final molasses by the same author shows 28.98% organic matter and out of the inorganic salts, silica, calcium, sulphites and sulphates to be the major constituents. Thus the suspended matter in syrup though small on percentage basis, is significantly high against the background of the requirements of plantation white sugar which is crystallised out from syrup and the suspended impurities in white sugar have thus their origin in the suspended impurities of syrup. All this points to the importance of treating syrup for eliminating the impurities in suspension which would contribute to the improvement of sugar quality. The new process of separately treating syrup by lime, phosphoric acid and flocculant followed by separation of impurities by floatation is a significant advance in the process of white sugar manufacture or for that matter any process which involves application of purification technique to syrup for removal of precipitated impurities would help improve quality of sugar and further crystallisation process.

6. SCALES

6.1. Cane juice contains besides sugars small amounts of organic and inorganic compounds and during clarification process the nature of these nonsugars undergoes some transformation. In the evaporator, as concentration of juice proceeds, the salts in solution are thrown out of solution as their solubility is exceeded and in consequence the salts in suspension are deposited on the heating surface. The composition of mineral matter is characterised by presence of a number of cations like Fe\(^+\), Al\(^+\), Ca\(^+\), Mg\(^+\) and anions like SO\(_4\)\(^-\), Cl\(^-\), SO\(_4\)\(^-\), PO\(_4\)\(^-\), SiO\(_3\)\(^-\). Besides these there are organic acid salts and decomposition products of organic compounds due to action of heat. In the evaporator operation the water to soluble components ratio changes from 85 : 15 to 10 : 15 and on reaching supersaturation various compounds are precipitated resulting in fouling of heating surfaces of different bodies to varying degree. Incrustation on the inside of the tubes resulting from the reduction in solubility of inorganic and organic compounds of the juice is a phenomenon commonly met with in the cane sugar industry and the factories have to periodically stop the entire process of manufacture to clean the fouled heating surfaces. The composition of scale is determined by the natural constituents of raw-juice as also the clarification process followed and in general the scaling in factories following sulphitation process is more severe than if they adopt carbonation or defecation of juice. In the normal course without adoption of scale inhibiting chemicals, the sulphitation mills in India have to stop for cleaning operation of evaporator once in 10-20 days.

6.2. Factors contributing to scale formation—Apart from the natural composition of raw juice there are some factors connected with the evaporator design as also the operation and the control of the clarification process which decide the composition and intensity of scale deposition. These are as under—

(i) In clarification lack of control on pH, temperature and time of reaction can lead to high calcium salts in clear juice resulting from the reaction of lime with decomposition products of reducing sugars which are usually organic acids,
major among them being lactic acid. The calcium salts are major constituents of scale.

(ii) The quality of lime with respect to composition is known to create problems in the evaporation. Use of lime with high amount of Silica and Sulphates leads to formation of hard scale.

(iii) Fine suspended impurities in clear juice are deposited on the inside of the tubes of bodies in the first stage of evaporator operation.

(iv) The juice must have rapid passage through the heating surface for which the circulation of juice in the bodies has to be good. Lack of proper circulation leads to certain pockets of calandria developing more incrustation.

(v) Whenever an evaporator is operated below its rated capacity the scaling is more as higher retention time of juice favours scale deposition. Less scale deposition is observed in evaporator designs with lower retention time than the conventional Roberts bodies.

6.3. Nature of scale—In sulphitation plants the scale consists mainly of—

(i) calcium phosphates, calcium sulphites, calcium sulphates, calcium oxalates,

(ii) Silica,

(iii) Oxides of iron and alumina

(iv) magnesium salts.

Generally the sulphites and sulphates are more pronounced in the sulphitation factories while the phosphates of calcium predominate the scale composition of defecation plants. In carbonation factories calcium oxalate is present in substantial amount in the evaporator scale.

Usually the scale in the first body is rich in calcium phosphate while silica, sulphites and sulphates are found in large amount in the scales of the last and the penultimate body of the evaporator. The phosphate scales are easy to remove while the scales containing silica, sulphites and sulphates are hard in nature. Similarly calcium salts of organic acids of juices notably the calcium aconitate also are found in the latter bodies along with sulphites.

Scales are formed mostly at the lower portions of the tubes while the top portions of tubes are less coated with deposits.

Typical analyses of scales from some Indian factories producing plantation white sugar by sulphitation are presented in Table 1 & 2.

6.4. Effect on heat-transfer—

In factory operation the effect of fouling of the heating surface of evaporator is known from the brix of syrup which goes on dropping as the incrustation on tubes accumulates. Thus the incrustation has marked influence on the heat transfer rate. The heat transfer rate from the heating medium to the juice in the tube is determined by resistance to heat offered by
(a) the air or water in the steam or vapour.

(b) metal of the tube

(c) scale.

Out of these the resistance due to scale is hundreds of times that due to the copper or brass or steel of which the tubes are made. This can be represented as—

\[ R = R_1 + R_2 + R_3 \]

and since conductance varies inversely as the resistance to flow of heat the total conductance of heat will be a cumulative effect of above factors represented as—

\[ U = \frac{1}{R} = \frac{1}{R_1 + R_2 + R_3} \]

From the above, it will be obvious that scale plays a very crucial role in determining the overall heat transfer rate by bringing down the heat conductivity from the vapour or steam to juice in the operation of the evaporator. With gradual building up of scale during running the thickness of scale deposited on the inside of the tube increases thereby contributing to the resistance to flow of heat. This explains the lowering of rate of evaporation after some days in the evaporator, which manifests itself in the lowering of brix as the period after cleaning advances.

6.5. Methods of removal of scale—

For descaling of evaporator the cane grinding is stopped for long period, varying from 16 to 36 hours, the usual stoppage being of 24 hours. The methods of removing the scale can be classified as

(a) Mechanical

(b) Chemical

(c) Combination of both chemical and mechanical methods.

In Indian factories the evaporator cleaning usually consists of two steps—

(i) boiling of chemicals in vessels to partially remove the scale followed by

(ii) Mechanical removal of adhering scale by brushing preceded sometimes by cutter operation.

Besides the caustic soda, sodium salts and hydrochloric acid various chemicals have found wide use in chemical boiling but ultimately every factory has to choose the proper treatment on the basis of the costs involved, efficacy of the chemicals and time saved in cleaning. In the case of mechanical cleaning, manually scraping the tubes with the help of brushes or cutters fitted to long steel rods which was prevalent 3-4 decades back has now been abandoned in favour of motor driven flexible shafts with brush or cutter attachments. In sulphitation plants evaporator cleaning only by mechanical means is not possible in India and the usual practice is to boil out chemicals first before mechanical descaling operation.
6.5.2. Chemical cleaning

(i) Procedure—After the evaporator calandrias are filled with water, the chemicals are added and boiling started after closing the manholes. It is always desirable to boil each body at high temperature and steam connections are provided in the vapour space of the calandria. The vapours emanating from the boiling liquid are let off from the top sight glass located above the manhole. After boiling for 1 to 3 hrs. the chemicals are drained out, the bodies are washed with cold water and the mechanical cleaning started. The different chemicals employed are as under—

(a) Hydrochloric acid—Hydrochloric acid removes phosphates, carbonates and organic acid salts. Dilute acid is boiled after addition of suitable inhibitor which inhibits corrosive action of hydrochloric acid on steel plates of the evaporator body. Addition of fluoride to hydrochloric acid helps dissolve silicates whenever the Silica content is high. Sodium bifluorides are found to be effective for this purpose. The disadvantage with hydrochloric acid is that it is highly corrosive, dangerous to handle and the vapour escaping from acid boiling have also acid reaction. It is however cheap and with proper dosing of inhibiting reagent can be used with good scale removing property. Boiling solution is sometimes mixed with aluminium and ferric sulphate to reduce the corrosive action of hydrochloric acid. But now a days different new synthetic compounds have been introduced as inhibitors and have been found to be quite effective. Nevertheless this acid cannot be used for cleaning stainless steel tubes, since stainless steel is attacked by hydrochloric acid.

(b) Sulphamic acid—This is a solid inorganic acid free from corrosive properties associated with hydrochloric acid and is easy to handle. The acid solution forms soluble calcium salts. The sulphamic acid is however hydrolysed at boiling temperature with the formation of sulphuric acid and it is thus desirable to avoid heating to boiling point while using this acid. Sulphamic acid with the addition of inhibitor has been found to be very effective in removing hard scales in Sameerwadi factory in India. The only disadvantage with this acid is its higher cost compared to hydrochloric acid for an equivalent scale removing action.

(c) Alkali—Soda boiling of evaporator bodies has been an established practice in sugar mills since long. The common procedure is to use sodium hydroxide along with small quantities of washing soda (15-30% of the caustic soda) for boiling. High concentration of alkali and high temperature favour dissolving and softening even hard scales and the experience in sulphitation plants in Deccan Sugar Industry shows that 20-25% caustic soda solution with washing soda boiled for 2-4 hours, in the last two bodies of evaporator is effective in softening hard scale and removing part of incrustation. Soda hydrolyses the organic compounds and the sulphates as also sulphites of calcium. Concentrated caustic soda solution boiling at high temperatures decomposes silica compounds as also sulphates and sulphites of calcium and is thus recommended for the last two bodies of evaporator. The soda boiling converts sulphates and sulphites of calcium into carbonates and decomposes the organic compounds thereby
bringing about disintegration of cohering scaling components, which then can be easily removed by brushing.

For economic reason good practice is to prepare caustic soda solution in a tank located below the evaporator and circulate the same by means of pump and necessary piping connected to evaporator bodies. After each boil out the alkalinity of the solution will go down and with repeated use the accumulation of organic matter and particularly fatty acids, will impart foaming property to the soda solution. Before each cleaning it is essential to check the NaOH content and replenish the caustic soda.

Other chemicals—

(d) EDTA—This is sodium salt of ethylene diamine tetracetic acid with property to form complexes with metallic cations and dissolving calcium and magnesium salts. This chelating agent dissolves calcium ions above pH 3, magnesium ions above 2 pH and iron in the pH range of 2 to 7, but has no action on silica. EDTA because of its high price cannot be discarded after use but can be used a number of times after regeneration. A solution of EDTA at 6.0 pH is sprayed and circulated for few hours and the spent solution collected in a tank is treated with sulphuric acid for lowering the pH to 3.0 Calcium salts are precipitated out as sulphates which settle down, while the supernatant liquid is taken out and treated with caustic soda for reuse. Thus variation in the stability of chelates of different ions is made use of in regeneration of spent solution of E.D.T.A.16 Though effective, the EDTA has not found wide acceptance as cleaning chemical on account of high cost.

(e) Fluorides—Sodium bifluoride which is highly soluble in water is added to hydrochloric acid solution for dissolving silica. Sodium fluoride at low pH of 2-3.5 forms silicium tetrafluoride and is thus effective for removing silica scale.

(f) Miscellaneous reagents—

(i) Dilute final molasses solution if allowed to ferment in the calandria and kept for some time loosens the scale adhering to tubes but this practice is followed only at the end of the crushing season. Addition of 5% molasses during boiling with hydrochloric is reported to prevent damage to steel or brass tubes of evaporator bodies.

(ii) Common salt is added during soda boiling in the proportion of 10-25% of the caustic soda used.

(iii) Wetting agents are added to boiling chemicals for improving the effectiveness of alkali but scientific data relating to their use is lacking.

(iv) Inhibitors are added to hydrochloric acid to prevent corrosive action on steel parts of the body. The proportion of inhibiting agents in the acid should be carefully worked out after carrying out laboratory tests in which loss of iron from a mild steel plate boiled in the inhibited hydrochloric acid is determined.
6.5.3. **Mechanical cleaning**—Modern mechanical cleaning equipment consists of a flexible shaft driven by electric motor and encased in protective sheath. To the open end of the shaft is fitted descaling cutter or brush. The cutter has serrated rollers loosely fixed in the shafts of the tool. The tools or brushes are inserted in the tubes and moved up and down. The speed of rotation of shaft is around 3000 rpm. and since the workers have to operate the shafts in the vessels the motors are supplied with power at 24 volts by installing voltage transformers. The cutter tools are used only when scales are hard and difficult to remove by brushes. Otherwise, brushes are employed. In most of the factories running the cutters is followed by brushing with the help of flexible shaft fitted with steel wire brushes. One disadvantage with descaling with cutters is the damage to the tubes caused by the cutting edges of the tool.

In place of electric motors compressed air drive has been used but in India electric driven flexible shafts are employed for cleaning.

6.6. **Procedure followed in cleaning evaporator**—After the juice flow to the evaporator is stopped, each body is drained and water passed through each body subsequently. In most of the sulphitation plants both acid and alkali boiling are practiced, followed by mechanical scraping and brushing. According to author's experience in regard to cleaning of evaporator in the Deccan Sugar Factories where the tubes are heavily scaled, the procedure of cleaning a quadruple which can give good results is as under—

(i) As open boiling at high temperature is more effective man vacuum boiling the vapour side of calandrias of last two bodies of quadruple in which scale is heavy and difficult to remove as also second body is provided with live steam connections. The first body is boiled with exhaust steam. The vapours are allowed to escape from the top sight glass openings located in the upper part of the bodies.

(ii) 1-2% hydrochloric acid is boiled in all bodies of the evaporator, the duration varying from one hour in the case of last two bodies and two hours with first two bodies. The inhibitor is added to hydrochloric acid in the predetermined dose. In case the scale is hard and contains high amount of silica, sodium fluoride or ammonium bifluoride is added to the body.

(iii) The acid boiling is usually preceded or followed by soda boiling in the last two bodies for 3-4 hrs. The caustic soda solution is prepared in a special soda storage tank constructed below the evaporator floor and soda circulated through the evaporator calandrias which are heated by steam. The soda from the evaporator bodies is stored in the tank which is connected to a pump for circulation of soda. Each time before reuse the concentration of soda is restored by adding caustic soda, sodium carbonate and some times common salt. The proportion of each of the latter two chemicals to caustic soda is normally maintained 4 : 1 or 1.5. Spraying of hot soda on top tube plate, through nozzles instead of filling the calandria is also practised in some plants. The boiling solution contains 15-20% caustic soda.

(iv) After washing out the soda and cooling the bodies the mechanical cleaning follows. The tubes in first two bodies of quadruple can be cleaned by brushing while for last
two bodies brushing is usually preceded by operation of cutter head. Needless to state motor driven flexible shafts are to be employed for mechanical cleaning.

(v) The sludge accumulating in the soda storage tank mostly consisting of scale is let out, when the tank is emptied. The scales in the evaporator bodies are collected for analysis by inserting steel rods in different bodies, which are removed before cleaning operation, and the scales analysed, for knowing the variations in the composition of scale from time to time in the course of the crushing campaign. The spent boiling liquors have also to be analysed for the causting soda content.

6.7. In Indian industry the total mill stoppage for evaporator cleaning varies from 16-30 hours but every endeavour is required to bring down this time loss which not only hampers processing of cane but also results in some inevitable loss of sugar due to stagnation of materials in process house and also increases fuel consumption. The total cycle of operation of cleaning the evaporator under Indian conditions is as under—

(i) Liquidation of evaporator 1-1½ hrs.

(ii) Rinsing with water 1/2 hr.

(iii) Chemical boiling 3-5 hrs.

(iv) Draining the bodies 1 hr.

(v) Mechanical cleaning 6-8 hrs.

(vi) Total time for evaporation cleaning 12-16 hrs.

(vii) Total time lost for crushing 16-24 hrs.

6.8. Steps for controlling scale deposition—

6.8.1. Notwithstanding the inevitability of scale formation in the evaporator bodies it is essential to take steps to reduce scale development by two methods viz. (i) Correct clarification technique and control of reactions, (ii) use of anticalents.

(i) Apart from proper dosing of lime, rigid control on different parameters like pH, time of contact of reactants, temperature as also the quality of lime go a long way in controlling scale deposition. The temperature of sulphited juices has to be 100°-102°C for completion of calcium sulphite reaction.

(ii) Underutilisation of the heating surface accelerates scale deposition due to longer residence of juice and low circulation rate. High velocity of circulation is conducive to low scale formation. Thus the evaporator should be operated to full capacity and moreover the design of evaporator vessels should be favourable for rapid circulation of juice in the calandria.

6.8. For reducing scale formation and modifying its character phosphate addition to clear juice advocated first by P. Honig is widely practised in Indian sulphitation plants. The phosphate also inhibits destruction of reducing sugars. Phosphate increases solubility of calcium sulphite and lowers the super saturation of calcium salts thereby reducing scale deposition.
Solution of Tetraphosphogluconate of lime when added to clear juice before entry into evaporator and also to the juice entering last body of evaporator has given good results according to experience in Cuba. The dosage would vary from 10-20 ppm. In Indian industry, however, this chemical has not found favour with the factories.

6.8.3. New additives—New synthetic additives have been introduced in recent years which are reported to have given good results in sulphitation plants. These are polymers based on acrylic acid which when mixed with the liquid to be evaporated act in three ways—

(i) These compounds increase solubility by bringing down the supersaturation level of salts responsible for incrustation.

(ii) The polymer molecules by attaching themselves at new crystal nuclei prevent growth of crystals of salts.

(iii) The salt crystals are modified by the synthetic polymer and not allowed to develop which renders the scale soft. Aggregation of precipitate particles is prevented by polymers and the salt crystals remain in suspension.

These chemicals are used in the proportion of 7-10 p.p.m. of juice and multipoint addition of dilute solution is desirable. The dilute solution of additive should be fed in equal doses at the clear juice entry to evaporator, before last body and also before the penultimate body. In India these chemicals are marketed under different trade names and have been found effective in reducing the periodicity of cleaning by 50% besides rendering the scales soft and easy to remove mechanically. In Deccan tract where the scales are heavy the use of new scale preventing chemicals has been found useful.

6.8.5. Electromagnetic devices—The juice is passed through electric or magnetic field whereby the salts get ionised and are supposed to remain in suspension. This is a simple apparatus consisting of tube mounted in the passage of juice. Positive results with regard to the efficacy of these devices are however not available and their use has not become universal.

6.9. In respect of the problem of incrustation formed on heating surface certain points have to be borne in mind while deciding upon the methods of cleaning.

(a) On cleaning day complete scale removal is absolutely essential since any incrustation remaining on the tubes will lead to rapid scale deposition by providing nuclei to salts which reach supersaturation during boiling. Thus thoroughness in cleaning operation has to be assured even if it be at the cost of chemicals or labour or the time involved.

(b) Greater emphasis has to be laid on chemical treatment of heating surfaces as the mechanical cleaning by scrapers or brushes will be effective only if the scale is softened or partially dissolved. Too much use of cutters is fraught with the danger of damage to tubes but the brushing is comparatively safe.

(c) Any new chemical to be tried out on large scale for scale removal must be carefully tested in the laboratory by treatment of scales collected. Its effects on corrosion of materials of the body as also efficacy in descaling have to be thoroughly studied before it is introduced in the plant.
(d) Every factory always strives to reduce the time loss on account of periodical cleaning, which constitutes half to three fourth of the total mill stoppage in a season. Some factories have spare bodies for evaporator, to be used in place of last two bodies after their heating surfaces get fouled. Such arrangement of standby bodies calls for elaborate vapour and other connections. Accumulation of scale necessitates raising the steam pressure in the calandria of first body for maintaining the syrup brix of 60° - 65° and this provides indication for closing the fouled bodies and bringing spare clean bodies into operation.

TABLE 1
SCALE COMPOSITION IN INDIAN FACTORIES
(Last two bodies)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Component</th>
<th>Deccan*</th>
<th>North India**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Organic matter</td>
<td>7-12%</td>
<td>35-38%</td>
</tr>
<tr>
<td>2.</td>
<td>Silica SiO₂</td>
<td>25-50%</td>
<td>0.30-0.4%</td>
</tr>
<tr>
<td>3.</td>
<td>Fe₂O₃, Al₂O₃</td>
<td>2.5-10%</td>
<td>0.2-4.0%</td>
</tr>
<tr>
<td>4.</td>
<td>CaO</td>
<td>12-25%</td>
<td>30-40%</td>
</tr>
<tr>
<td>5.</td>
<td>SO₄</td>
<td>1-10%</td>
<td>21-30%</td>
</tr>
<tr>
<td>6.</td>
<td>Phosphate</td>
<td>1.5-10%</td>
<td>1.1-10.0%</td>
</tr>
</tbody>
</table>

7. SCALING ON THE OUTSIDE OF THE CALANDRIA TUBES

On the vapour side of the calandrias thin film of scale is observed after some time which has its origin in the

(i) distillation products of the lipids i.e. the fatty acids from sugarcane,

(ii) corrosion products of vapour pipes.

(iii) Occasional entrainment.

This scale has a perceptible influence on impeding the heat-transfer rate if not removed regularly and author knows of instances of severe drop in evaporator efficiency in factories which have not cleaned vapour side of calandrias for 10-12 years. This scale is removed in the offseasons by different methods as under—

(i) Some factories which had not cleaned the vapour side for some years have found it more expedient to remove the tubes from the calandrias, clean the tubes and fit them

back which required replacement of 7-8% tubes by new ones. This method requires highly skilled labour and is thus costly but can be practised only if the vapour side of calandria has not been cleaned by chemicals for a number of years, at regular intervals.

(ii) Vapour space can be filled with dilute solution of molasses which is allowed to ferment and after it is let out, the calandria flushed with water. This will help eliminate the rust.

(iii) Water and Kerosene are filled and allowed to flow out at extremely slow rate to allow the tube surfaces to be cleaned of fatty matter coating.

(iv) Dilute hydrochloric acid with proper dose of inhibitor helps remove the inorganic matter and rust.

(v) Honig recommends the use of .2% acetic or formic acid combined with 1/2% nonfoaming detergent which when circulated through the calandria by removing a few tubes, eliminates most of the scale, restoring the heat transfer property.¹⁷

(vi) A method of cleaning vapour side, mentioned by Baikow¹⁸ requires use of 0.6% of caustic soda solution containing about 0.6% KMnO₄. This solution at 60°C is fed to calandria vapour side and heated to 100°C. It is allowed to remain in the calandria for 24 hrs. and drained out. This treatment is followed by contact of dilute hydrochloric acid mixed with iron sulphate heated to 94°C, for 45 minutes. After discharge of chemicals washing and rinsing follows. This procedure according to him maintains the vapour side clean for long time.

(vii) Treatment with hot concentrated caustic soda helps remove the greasy matter and organic coating.

The cleaning of vapour side should be carried out at the end of the crushing campaign every year to prevent accumulation of scale. During running entrainment has to be prevented to check fouling of the exterior of tubes.

8. CONTROL AND INSTRUMENTATION

8.1- Control of evaporator operation rests on—

(i) regulated feed to each vessel

(ii) maintenance of proper levels in bodies

(iii) exhaust steam pressure and temperature

(iv) vacuum in the last body.

Since the overall performance of the evaporator is judged by the brix of syrup obtained throughout the run i.e. during period between two shut-downs for cleaning and the steam economy of the process of manufacture is determined by the efficient working of this station, rigid control at this station merits special attention of the technologists. Deviation from the norms set for each of the above control parameters disturbs the function of the evaporator in various ways as discussed below—
(i) Fluctuations in juice feed rate and uneven levels of juice lead to poor circulation of juice in a vessel, which in turn promotes deposition of scale in the tubes besides giving low rate of evaporation. Hence the importance of regulated feed and proper levels in bodies. Moreover with bodies having sealed downtake, the higher level in any body will allow thin juice to pass over to the next vessel thereby affecting brix of syrup.

(ii) Irregularity in the exhaust steam pressure caused by sudden draw of steam from pan station or stoppage of prime movers at mills affects the evaporation rate in the first and consequently the subsequent bodies. Fluctuations in exhaust supply to evaporator on account of steam draw from pan floor can be corrected by installing surplus valve in the exhaust line after the evaporator so as to ensure adequate steam supply to evaporator. Of equal significance is to ensure that the degree of superheat in the exhaust does not exceed 25° - 30°C since superheated steam has a poor heat transfer rate. Thus the temperature of exhaust has to be constantly watched.

In modern plants with separate condensers of new designs with independent air extraction system, the last body vacuum is stable unless leaks are developed in the evaporator bodies or the temperature of the injection water rises beyond limits due to failure of spray cooling of outlet water of condenser. Drop in vacuum in the last body brings down the vacuum of other bodies and consequently the evaporation rate as also brix of final syrup.

8.2. Instruments—The evaporator operator can control the working of the evaporator station by observing temperatures, pressures or vacuum and juice levels in the bodies. Every vessel thus must be equipped with temperature and vacuum or pressure gauges fitted both in the vapour space of the calandria as also the vapour space of the body. The juice levels can be observed in the level gauge glass of each body. Likewise flow of condensates from calandrias can be noticed by observing gauge glasses fitted to calandrias as also the sight glasses fitted in the outlets of calandrias. Thus by observing and monitoring the different parameters of operation the working can be controlled manually. Besides above, the brix meter is provided at the syrup outlet from last body. Thus with the help of all the gauges and meters a vigilant operator can control manually the operation of this station properly. To summarise it may be stated that the evaporator station must be equipped with the following gauges and meters for manual checking, observation and record:

(i) temperatures of vapour space and calandrias.
(ii) pressure/vacuum of bodies and calandrias.
(iii) pressure and temperatures of exhaust steam.
(iv) brix of syrup.
(v) levels of juice,
(vi) flow of condensates from calandrias.

8.3. Automation—Automatic control of the evaporator has the merit of eliminating disturbance in operation due to operator's errors of judgement and fluctuations in inputs thereby giving
consistently high brix syrup. This control system takes into account all the operating variables referred to earlier and functions in the following manner—The variables to be controlled are—

(a) Juice input,
(b) steam flow
(c) levels
(d) syrup brix
(e) final body vacuum

(a) For regulating juice flow it is essential to install a buffer tank for clear juice from which the rate of juice flow into the evaporator is regulated by the level controller. When the level of juice in the tank rises more juice is fed to evaporator while when juice level goes down the inflow to evaporator is reduced. The mean level of juice thus corresponds to the normal rate of production of clear juice. In the event of clear-juice level falling to the bottom condensate water is opened automatically to keep the evaporator functioning.

(b) Steam flow rate to the evaporator first effect is controlled by signal pulses transmitted from pressure and temperature prevailing on the juice side.

(c) Level of juice in a body is controlled by regulating the feed to the body on the basis of appropriate signals from the sensor.

(d) Brix meter senses the syrup brix and transmits signals for either adjusting
   (i) juice flow rate or
   (ii) steam flow
   (iii) recirculating the syrup leaving the last body if the brix is low or increasing the rate of syrup flow if it is high by opening the valve more are automatic operations.

(e) Control of final body vacuum regulates the injection water flow to condenser on the basis of absolute pressure in the vapour space. Complete automation of evaporator will incorporate the above systems and computer controller has been introduced in the industry in recent years. In some factories only level controllers have been adopted, the remaining operating parameters being manually controlled.

9. REACTIONS IN EVAPORATOR AND PRECAUTIONS IN OPERATION

9.1. Inversion—As stated earlier in the preevaporator and first body of evaporator sucrose inversion is observed if the residence time is high and temperatures of boiling juice are also high. Every factory has to find out the limits of high temperature to which the juices should be heated without sucrose getting decomposed. Some Indian factories have recently reported inversion occurring in the double effect vapour cell. If the pH of juice is well controlled it is possible to minimise the inversion loss by controlling the temperature and maintaining normal feed of juice to the evaporator.
9.2. Reducing sugars—Reducing sugars undergo transformation under influence of heat with formation of organic acids, caramel and other products. Addition of phosphate to clear juice helps prevent destruction of reducing sugars since out of the two hexoses termed as reducing sugars fructose is highly sensitive to heat and is destroyed by heat. However, the dose of phosphate has to be determined by conducting laboratory experiments. A dose of 32-64 ppm. $P_2O_5$ is considered optimum from this point of view. pH of juice at the temperature of boiling should be determined in view of the depressing effect of temperature and the effects of the pH at operating temperature on inversion need to be studied at each factory.

9.3. Technical control—Every hour the readings of temperatures and pressure or vacuum in the calandria and juice chamber of each body should be recorded and any deviations from normal investigated. Similarly the hourly readings of brix of outgoing syrup should be recorded. The temperatures and vacuum readings serve to indicate the gradual build up of scale in bodies.

As regards the analytical work to be carried out in the laboratory in the direction of proper control of operations following points need special attention:

(a) Brixes of juices leaving each body need to be determined off and on to know the functioning of each vessel. However the brix of outgoing juice of the preevaporator has to be found regularly in view of the important role of this vessel on the steam economy of the process.

(b) The glucose/sucrose ratio at the inlet and outlet of the evaporator throws light on the inversion of sucrose as also destruction of reducing sugars.

(c) The condensates and condenser water are to be analysed regularly for sugar tests and pH to check entrainment. Under normal conditions high juice levels or tube damage or sudden changes in vacuum can be the cause of entrainment.

(d) Analyses of scales collected before chemical boiling as also the spent acid and alkali after chemical boiling throw light on the composition of scale and the efficacy of chemical treatment for descaling.

9.3. At the end of the crushing campaign the heating surfaces are to be thoroughly cleaned and during the prolonged shut down of the off-season following regular maintenance jobs are to be carried out:

(i) the vapour side of calandria of each vessel is to be chemically treated for removal of adhering coating and deposits,

(ii) vapour pipes have to be taken out for cleaning the inside surface which develops rust. After 7-8 years' working the pipe thickness should be checked every year.

(iii) Walls of vessels are scraped and cleaned as some scale invariably deposits on the inside of the cylindrical top vessel.

(iv) the entrainment catchers are cleaned.

(v) all the valves are removed, repaired wherever required tested and refitted,
(vi) the pumps and various indicating gauges are opened; checked, repaired and tested,

(vii) the calandrias have to be tested for leaks by pumping water at \(2.5 - 3.0 \text{ kg/cm}^2\) pressure.

(viii) Before commencement of new crushing campaign the evaporator station is kept ready after fitting pipes, valves gauges etc. and time taken for reaching the desired vacuum i.e. 625 - 650 mm in the last body is noted.

10. INSULATION

To prevent loss of heat to the surroundings, the vessels of evaporator station along with all the piping conveying steam or hot fluids have to be thoroughly insulated. Sheets of felt of about 25 mm. thickness are wrapped round the metal surface of the bodies and covered with long wooden strips which are fixed to circular wooden battens attached to the steel belt of the vessel. Old practice of applying asbestos magnesia as insulating material has given place to covering hot surfaces by fibre glass sheets which are easy to handle. The air-gaps constitute a substantial volume of the fibreglass bundles and the still air enmeshed in the fibre bundles provides the best insulating material. Except the vapour pipe of the last vessel going to condenser all the vapour pipes have to be thoroughly insulated by fibre glass sheets or asbestos magnesia. In the present trend towards achieving maximum heat economy by elaborate vapour bleeding the vapour conveying pipes need to be properly insulated. The hot surfaces of valves and flanges of pipes and bodies have to be protected from loss of heat by proper insulation since any bare metallic surface would cause substantial loss of heat.
REFERENCES

2. F. bid. P. 143-144.
   P.M 84-M92.
   also J.C. Bhargava, R.N. Agnihotri and P. Sanyal. Ibid, p. 115-152.
### TABLE 2
COMPOSITION OF EVAPORATOR SCALE

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Component</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Loss on ignition %</td>
<td>31.12-38.1</td>
</tr>
<tr>
<td>2.</td>
<td>SiO₂ %</td>
<td>0.26-0.40</td>
</tr>
<tr>
<td>3.</td>
<td>CaO %</td>
<td>29.86-38.71</td>
</tr>
<tr>
<td>4.</td>
<td>MgO %</td>
<td>0.11-0.24</td>
</tr>
<tr>
<td>5.</td>
<td>Fe₂O₃ %</td>
<td>0.11-0.24</td>
</tr>
<tr>
<td>6.</td>
<td>SO₃ %</td>
<td>20.42-30.75</td>
</tr>
<tr>
<td>7.</td>
<td>P₂O₅ %</td>
<td>1.1 -1.76</td>
</tr>
<tr>
<td>8.</td>
<td>Al₂O₃ %</td>
<td>0.21-0.30</td>
</tr>
<tr>
<td>9.</td>
<td>Na₂O %</td>
<td>0.01-0.08</td>
</tr>
<tr>
<td>10.</td>
<td>K₂O %</td>
<td>0.02-0.15</td>
</tr>
<tr>
<td>11.</td>
<td>Chlorides %</td>
<td>0.03-0.05</td>
</tr>
<tr>
<td>12.</td>
<td>ZnO %</td>
<td>0.02-0.03</td>
</tr>
<tr>
<td>13.</td>
<td>CuO %</td>
<td>0.10-0.15</td>
</tr>
</tbody>
</table>

1. VAPOUR BLEEDING AND STEAM ECONOMY

1.1. Evaporator station occupies an important place in the process of white sugar manufacture from the point of view of steam economy for two reasons: firstly the brix of syrup determines to a large extent the steam load on the pan station; secondly the vapour bleeding from different bodies brings down the total steam consumption in process. Vapour bleeding from different bodies is quite common in modern sugar plants and the design of the evaporator takes into account this important aspect of the steam economy in the process. Without any vapour bleeding the steam consumption in a white sugar plant is as under—

1. Steam for juice heating 12-13% cane
2. Steam for quadruple effect evaporator 18-19% cane
3. Steam for pan boiling 22-24% cane
4. Steam for direct use in centrifugals etc. 5% cane

Thus the steam requirement for juice heating and pan station accounts for nearly 60% of the total requirement of the process, a fact which points to the necessity of employing vapour for these two operations from the evaporator bodies. With recent trend of employing high levels of imbibition at mills the juice percent cane is 100-105 and unless elaborate vapour bleeding from evaporator bodies is resorted to, the steam and fuel balance of sugar-mill will be completely out of control.

1.2. Following the Rillieux second principle that the steam saving on account of use of vapour from a particular effect of evaporator for juice heating and pans will be equal to the quantity of vapour withdrawn multiplied by the serial number of the effect from which vapours are drawn and divided by the total number of effects, greater steam economy is achieved by robbing maximum vapour from latter bodies of multiple effect evaporator. A natural corollary of this principle is that minimum amount of vapour should go to the condenser. Thus, ideal vapour bleeding arrangement envisages the withdrawal of vapours from all the bodies of a multiple effect system, including the last body. The heating surfaces of the evaporator bodies have to be determined taking into consideration the utilisation of vapour from different bodies for process operation. Moreover, higher vapour withdrawal means increase in steam consumption at the evaporator.

2. In a sugar factory the high pressure steam is fed to prime movers for generation of electric power, for mills and sometimes few other units, the exhaust being utilised for running the process. In a modern plant the exhaust requirement is supplemented by bleeding
reduced live steam into the exhaust line for which a steam pressure reducing station is installed. The system of vapour bleeding and the steam economy achieved therefrom must be planned in such a way that—

(i) the exhaust production will not outpace the steam requirement for process as otherwise exhaust will be blown into atmosphere,

(ii) this obviously necessitates the installation of prime movers which give minimum exhaust steam per K.W. of power generated,

(iii) the live-steam bleeding into exhaust line is controlled automatically,

(iv) the evaporator bodies like preevaporator or first body heated by exhaust steam receive constant supply of steam of proper pressure,

(v) the temperatures and pressures in the vapour cell and first body of evaporator have to be maintained such that inversion of sucrose or destruction of reducing sugars are avoided,

(vi) Heating surfaces of the different bodies and particularly first body have to be adequate.

A vapour cell is installed for furnishing vapours to pan station as also the final juice heating and with fluctuation in the demand for vapour from pan station on account of batch operation of pans the vapour generation will undergo variations. Thus the design of evaporator station with respect to vapour bleeding from different bodies decides to a considerable extent the steam requirement of the process of sugar manufacture which is bound to be high thanks to the need for producing bigger size sugar grains and maintaining high standard of colour. Against the background of the plantation white sugar manufacture process as practised in India different methods of vapour bleeding are in vogue depending on the size of the plant as also the design and age of the evaporator station. The present methods of vapour utilisation for juice heaters and pan station have evolved as a result of the experience gained in the area of efficient use of steam and steam economy in process in the past three decades and introduction of new equipment designed to facilitate the use of vapour from different bodies of evaporator as also the preevaporator.

3. The major system of multiple effect evaporator together with arrangements for vapour bleeding as adopted in modern sugar factories are as under—

(i) Quadruple effect with vapours drawn from first effect for raw-juice heating and partial heating of sulphured juice.

(ii) Vapour bleeding from quadruple for—

(a) heating of raw-juice partially from 4th body and second body,

(b) partial heating of sulphured juice by first body vapours.

(iii) Heating of raw-juice by 3rd body vapour of quadruple and partial heating of sulphured juice by first body vapours.
(iv) Quintuple effect evaporator with vapour bleeding from 3rd body for raw-juice heating and from 1st body for partial heating of sulphured juice.

(v) Vapour cell and quadruple—Preevaporator vapours for boiling of pans and use of vapours
(a) from 2nd body for raw-juice heating,
(b) from first-body for sulphured juice heating upto 90°-92°C

(vi) Vapour cell and quintuple—
(a) Vapour utilisation from vapour cell for pans,
(b) Vapours from 3rd body for raw-juice heater,
(c) Vapours from 1st body for sulphured juice heating.

(vii) Double effect evaporator as Preevaporator and Quadruple
(a) Vapours from first effect of vapour cell for final massecuite boiling and final heating of sulphured juice.
(b) Vapours from second body of vapour cell for boiling A & B massecuite pans and first heating of sulphured juice.

(viii) Raw juice to be heated by second body vapours of the quadruple.

4. STEAM SAVING BY VAPOUR BLEEDING—THEORETICAL
4.1. If E is the total water evaporated in a multiple effect evaporator of n effects the steam consumption of the evaporator is E/n. For a quadruple the steam required will be E/4. Assume that vapours are drawn from all the bodies of quadruple as follows—

\[ x_1 \text{ from 1st body} \]
\[ x_2 \text{ from 2nd body} \]
\[ x_3 \text{ from 3rd body} \]
\[ x_4 \text{ from 4th body} \]

for entire juice heating and pan boiling.

If steam required for juice heaters and pans, without any vapour bleeding = P

\[ P = x_1 + x_2 + x_3 + x_4 \]

Total steam required without vapour bleeding for Juice heaters, evaporator and Pans

\[ = P + \frac{E}{4} \] \hspace{1cm} ...(a)

Steam required for quadruple with vapour bleeding as above

\[ = \frac{E}{4} + \frac{3}{4}x_1 + \frac{2}{4}x_2 + \frac{1}{4}x_3 \] \hspace{1cm} ...(b)
Steam saving = \( a - b \)

\[ = \frac{1}{4}x_1 + \frac{2}{4}x_2 + \frac{3}{4}x_3 + x_4 \]  

...(c)

4.2. If a preevaporator is installed from which vapours \( V \) are used for bleeding.

Total evaporation in the quadruple = \( E - V \)  

...(d)

Steam for quadruple with vapour bleeding as above—

\[ = \frac{E - V}{4} + \frac{3}{4}x_1 + \frac{2}{4}x_2 + \frac{1}{4}x_3 \]  

...(e)

\[ \therefore \text{ Extra saving due to preevaporator } = b - c = \frac{V}{4} \]

4.3. Similarly for a quintuple assuming vapour withdrawn from 1st, 2nd, 3rd, 4th and 5th vessel as \( x_1, x_2, x_3, x_4 \) and \( x_5 \) respectively for entire juice heating and pan boiling without vapour bleeding steam for evaporator = \( \frac{E}{5} \)

\[ \therefore \text{ Total steam required for juice heaters, evaporator and pans } = \]  

\[ = \frac{E}{5} + x_1 + x_2 + x_3 + x_4 + x_5 \]  

...(f)

with vapour utilisation, steam for evaporator

\[ = \frac{E}{5} + \frac{4}{5}x_1 + \frac{3}{5}x_2 + \frac{2}{5}x_3 + \frac{1}{5}x_4 \]

\[ \therefore \text{ Steam saved } = f - g \]

\[ = \frac{1}{5}x_1 + \frac{2}{5}x_2 + \frac{3}{5}x_3 + \frac{4}{5}x_4 + x_5 \]  

...(h)

4.4. Vapour going to condenser = Steam for first body of evaporator - Total vapour withdrawn from different bodies—

\[ \therefore \text{ Vapour going to condenser from quadruple with vapour bleeding} \]

\[ = b - (x_1 + x_2 + x_3 + x_4) \]

\[ = \left( \frac{E}{4} + \frac{3}{4}x_1 + \frac{2}{4}x_2 + \frac{1}{4}x_3 \right) - (x_1 + x_2 + x_3 + x_4) \]

\[ = \frac{E}{4} - \frac{1}{4}x_1 - \frac{2}{4}x_2 - \frac{3}{4}x_3 - x_4 \]

5.1. In what follows are presented the calculations regarding the steam consumption of the entire process of plantation white sugar manufacture employing different systems of vapour bleeding and evaporator arrangements. It is an accepted fact that maximum utilisation of
vapours from the multiple effect evaporator envisages the minimum loss of vapour to the condenser. The efficiency of a multiple effect evaporation system as given by Staub & Paturau\(^1\) essentially takes into account the minimum loss of vapour to condenser. This equation for efficiency of multiple effect evaporator can be given as under—

$$\text{Efficiency} = 100 \left(1 - \frac{C}{E}\right)$$

Where C is the amount of vapour going to condenser per hour and E is the total amount of water evaporated per hour.

5.2. The assumptions which form the basis for the following calculations are—

(a) (i) Cane crushed 100 t.ch. and clear juice % cane 100.
     (ii) Clear juice brix 15.0.
     (iii) Syrup brix 60°.

(b) (i) Exhaust steam of 0.5 kg/cm\(^2\) for first body of multiple effect evaporator.
     (ii) Exhaust steam of 0.7 kg/cm\(^2\) for preevaporator.
     (iii) Vacuum in last body of evaporator 635 mm.

(c) (i) Raw juice of 35°C heated to 70°C.
     (ii) Treated juice or Sulphured juice at 65°C heated either in one or two stages to 102°C.
     (iii) Clear juice heated in a heat exchanger by steam to the required temperature corresponding that prevailing in the vessel to which it is fed, either first body or preevaporator.

(d) (i) Steam consumption of pan station is equivalent to 22% exhaust steam of 0.5 kg/cm\(^2\) pressure.

(e) Direct use of steam and unknown loss = 5% cane.

(f) Specific heat of raw, treated or clear juice is 0.90.

(g) To compensate for the loss of heat due to radiation during flow of steam or vapour through pipes a factor of 95% has been applied to the heat content of the heating medium.

(h) The hot raw-juice of 70°C is supposed to have been cooled during treatment with chemicals to 65°C and the clear juice leaving clarifier has temperature of 95°C. In effect the sulphured juice is heated from 65°C to 102°C while clear juice has to be heated from 95°C to the temperature of boiling fluid in the evaporator.

(i) The pressure drop in different vessels of the quadruple and quintuple decreases slightly from first to the last as advocated by Hugot\(^2\) and consequently the pressure distribution in the bodies will be based on the decreasing pressure drop.

The absolute pressures adopted for different bodies of quadruple and quintuple are as under—
Case 1  Ordinary quadruple—

1. Total Evaporation = \( \frac{60 - 15}{60} \times 100 = 75 \) t / hr.

2. (i) Steam requirement of the quadruple without vapour bleeding = 75 + 4 = 18.75 t.

(ii) Steam required for preheating clear juice by exhaust steam to the temperature of boiling taking into account B.P.R.

\[
\frac{1000 \times 100(104 - 5 - 95) \times 0.9}{0.95 \times 531.5} = 1.69 \text{ t.}
\]

3. Steam for raw-juice heating

\[
\frac{1000 \times 100(70 - 35) \times 0.9}{0.95 \times 531.5} = 6.24 \text{ t.}
\]

(iv) Steam for sulphured juice heating

\[
\frac{1000 \times 100(102 - 65) \times 0.9}{0.95 \times 531.5} = 6.60 \text{ t.}
\]

4. Steam for pans 22t.

5. Vapours going to condenser 18.751.

6. Total steam requirement

(a) Raw-juice heating = 6.24 t.

(b) Sulphured juice-heating = 6.60 t.

(c) Clear juice heating = 1.69 t.

(d) Steam for evaporator = 18.75 t.

(e) Steam for pans = 22.00 t.

(f) Miscellaneous steam consumption including losses = 5.00 t.

Total 60.28 t/hr.

of exhaust of 1.5 kg/cm\(^2\) absolute pressure

Total heat requirement = 32,038 x 10\(^3\) k cal/hr.
Case 2:

1. Quadruple with—

   (i) Vapour from 2nd body for raw-juice heating

   (ii) Vapour from 1st body for treated juice heating to 92°C; steam used for heating from 92°C to 102°C.

2. (i) \[ V = \frac{1000 \times 100 \times 0.9 (70 - 35)}{0.95 \times 540 \cdot 5} = 6.13 \text{ t.} \]

   (ii) \[ V = \frac{1000 \times 100 \times 0.9 (92 - 65)}{0.95 \times 537 \cdot 2} = 4.76 \text{ t.} \]

   (iii) \[ St = \frac{1000 \times 100 \times 0.9 (102 - 92)}{0.95 \times 531 \cdot 5} = 1.78 \text{ t.} \]

3. Steam for heating clear-juice = 1.69 t

4. Steam for ————

5. Total stea \[ \frac{75 + 6 \times 13 \times 2 + 4 \times 76 \times 3}{4} = 25.39 \text{ t.} \]

6. Vapour going to condenser
   
   = 25.39 - 6.13 - 4.76 = 14.50 t.

7. Total steam consumption—

   (i) Steam for heating of treated juice 1.78 t.

   (ii) Steam for heating of clear juice 1.69 t.

   (iii) Steam for evaporator 25.39 t.

   (iv) Steam for pans 22.00 t.

   (v) Miscellaneous as in Case I 5.00 t.

   \[ 55.86 \text{ t.} \]

   Total heat required = 29,689.6 x 10^3 K cal.
Case 3:

1. (i) Quadruple
   (ii) Raw-juice heated partially to 42°C by vapours from fourth body
   (iii) Raw-juice further heated by vapours from 2nd body
   (iv) Sulphured juice partially heated to 92°C by vapours from 1st body and further heated to 102°C by steam.

2. (i) Vapours for raw juice heating from 4th body
   \[
   \frac{1000 \times 100 \times 0.9(42 - 35)}{0.95 \times 565.6} = 1.17 \text{ t}
   \]
   (ii) Vapour from 2nd body—
   \[
   \frac{1000 \times 100 \times 0.9(70 - 42)}{0.95 \times 540.5} = 4.91 \text{ t}
   \]
   (iii) Sulphured juice heating from 65°C to 92°C as in Case II = 4.76 t.
   (iv) Steam for final heating of sulphured juice = 1.78 t.

3. Steam for evaporator
   \[
   \frac{75 + 4 \cdot 91 \times 2 + 4 \cdot 76 \times 3}{4} = 24.78 \text{ t}
   \]

4. Vapour to condenser = 24.78 - 1.17 - 4.91 - 4.76 = 13.94 t.

5. Total steam consumption (tonnes):
   (i) For sulphured juice heating 1.78 t.
   (ii) For clear-juice heating 1.69 t.
   (iii) For evaporator 24.78 t.
   (iv) For pans 22.00 t.
   (v) Miscellaneous 5.00 t.
   Total 55.25 t. exhaust steam

Total heat required per 100 t. cane = 29,365.4 \times 10^3 \text{ K cal/hr.}
Case 4:

1. (i) Quadruple
   (ii) Raw-juice heated by vapours from 3rd body
   (iii) Sulphured juice partially heated by vapours from 1st body to 92°C.

2. (i) Vapours for raw juice heating
   \[
   \frac{100 \times 1000 \times 0.9 \times (70 - 35)}{0.95 \times 552} = 6.00 \text{ t}
   \]
   (ii) Vapours from 1st body for treated juice heating to 92°C as in Case II.
   \(= 4.76 \text{ t.}\)
   (iii) Steam for final heating of treated juice \(= 1.78 \text{ t.}\)

3. Total steam for evaporator
   \[
   \frac{75 + 6 \times 1 + 4 \times 76 \times 3}{4} = 23.82 \text{ t.}
   \]

4. Vapours to condenser 23.82 - 6.0 - 4.76 \(= 13.06 \text{ t.}\)

5. Total steam consumption:
   (i) Treated juice heating \(= 1.78 \text{ t.}\)
   (ii) Clear juice heating \(= 1.69 \text{ t.}\)
   (iii) Evaporator \(= 23.82 \text{ t.}\)
   (iv) Pans \(= 22.00 \text{ t.}\)
   (v) Miscellaneous \(= 5.00 \text{ t.}\)

   Total exhaust steam \(= 54.29 \text{ t.}\)

Total heat for 100 t cane \(= 28,855.13 \times 1000 \text{ KCal.}\)

Case 5:

1. (i) Quadruple with vapour cell
   (ii) Preevaporator supplies vapours to all pans.
   (iii) Raw-juice heated by vapours from 2nd body.
   (iv) Treated juice heated to 92°C by 1st body vapours and further heated to 102°C by vapours from preevaporator.

2. (i) Steam of 0.7 kg/cm² pressure used for pre-evaporator,
   (ii) Vapours from pre-evaporator of 0.4 kg/cm².
(iii) Clear juice heated by 0.7 kg/cm$^2$ pressure steam.

3. Total vapours withdrawn from preevaporator
   = 22 + vapours for treated juice heating.

Vapours for treated juice-heating

$$\frac{1000 \times 100 \times 0.9 \times (102 - 92)}{0.95 \times 532.7} = 1.78 \text{ t.}$$

$$22 + 1.78 = 23.78 \text{ t.}$$

.: Total Evaporation in quadruple = 75.00 - 23.78 = 51.22 t.

4. Steam

$$= \frac{1000 \times 100 \times 0.9 \times (110 - 95)}{0.95 \times 528.9} = 2.85 \text{ t.}$$

5. (i) $\frac{51 \times 22 + 2 \times 6 \times 13 + 4 \times 76 \times 3}{4} \approx 19.44 \text{ t.}$

(ii) Vapours going to condenser

= 19.44 - 6.13 - 4.76 = 8.55 t.

6. Total steam consumption

0.7 kg/cm$^2$ pressure 23.78 + 2.85 = 26.63 t.

0.5 kg/cm$^2$ pressure

7. Total heat consumption

Total: $\frac{12,989 \times 9 \times 10^3}{27,074 \times 5 \times 10^3} \text{ k.cal.}$

Case 6:

1. Quintuple without vapour bleeding

2. (i) Steam for evaporator $= \frac{75}{5} = 15 \text{ t.}$

(ii) Vapours to condensor = 15 t.

3. (i) Steam for raw-juice heating = 6.24 t.

(ii) Steam for treated juice heating = 6.60 t.
4. Steam for clear juice heating

\[ = \frac{100 \times 1000 \times 0.9 \times (106 - 5 - 95)}{0.95 \times 531.5} = 2.05 \text{ t.} \]

5. Total steam of 0.5 kg/cm² pressure—

(i) Evaporator

= 15.00 t.

(ii) Raw juice heating

= 6.24 t.

(iii) Treated juice heating

= 6.60 t.

(iv) Clear juice heating

= 2.05 t.

(v) Pans

= 22.00 t.

(vi) Miscellaneous

= 5.00 t.

Total

= 56.89 t.

6. Heat consumption = 30,237.00 x 1000 x K cal.

Case 7:

1. Quintuple with vapour bleeding

(i) Raw-juice heating by vapours from 3rd body.

(ii) Treated juice heating by vapours from 1st body to 95°C and further heating to 102°C by steam.

2. (i) Vapours for raw-juice heating

\[ = \frac{100 \times 1000 \times 0.9 \times (70 - 35)}{0.95 \times 546.5} = 6.071. \]

(ii) Vapours for treated juice heating

\[ = \frac{100 \times 1000 \times 0.9 \times (95 - 65)}{0.95 \times 535.9} = 5.301. \]

3. (i) Steam for treated juice heating

\[ = \frac{100 \times 1000 \times 0.9 \times (102 - 95)}{0.95 \times 531.5} = 1.25 \text{ t.} \]

(ii) Steam for clear juice heating

= 2.05 t.

4. (i) Steam for evaporator

\[ = \frac{75 + 6.07 \times 2 + 5 \times 30 \times 4}{5} = 21.671. \]
(ii) Vapour to condenser
\[ = 21.67 - 6.07 - 5.30 = 10.30 \text{ t.} \]

5. Total steam consumption—
   
   (i) Treated juice heating 1.25 t.
   
   (ii) Clear juice heating 2.05 t.
   
   (iii) Evaporator 21.67 t.
   
   (iv) Pans 22.00 t.
   
   (v) Miscellaneous 5.00 t.

   Total: 51.97 t.

51.97 t of 0.5 kg/cm\(^2\) Steam

Total heat consumption per 100 t. cane
\[ = 27,622.00 \times 10^3 \text{ K cal.} \]

Case 8:

1. (f) Quintuple with vapour cell.
   
   (ii) Vapours from vapour cell withdrawn for pans and final heating of treated juice.
   
   (iii) Vapours from 3rd body for raw-juice heating.
   
   (iv) Vapours for partial heating of treated juice to 95°C from 1st effect as in Case 7.

2. (i) Vapours for raw-juice heating =6.07 t.
   
   (ii) Vapours for treated juice heating =5.30 t.

3. Steam for clear-juice heating =2.85 t.

   (0.7 kg/cm\(^2\) pressure)

4. (i) Evaporation in vapour cell
   \[ = 22 + 1.78 = 23.78 \text{ t.} \]
   
   (ii) Evaporation in quintuple = 75 - 23.78 = 51.22 t.

5. Steam for quintuple
\[ = \frac{51 \cdot 22 + 2 \times 6.07 + 4 \times 5.3}{5} = 16.91 \text{ t.} \]

6. Vapours to condenser
\[ = 16.91 - 6.07 - 5.30 = 5.54 \text{ t.} \]
7. Total steam consumption

(i) Steam at 0.7 kg/cm² = 23.78 + 2.85 = 26.63 t.
(ii) Steam at 0.5 kg/cm²
   (a) Steam for quintuple = 16.91 t.
   (b) Miscellaneous = 5.00 t.

Total = 21.91 t.

8. Total heat consumption—
   = 14,084.5 x 10³ K cal.
   + 11,645.2 x 10³ K cal

Total: 25,729.7 x 10³ K cal

Case 9:

1. (i) Quadruple with double effect preevaporator.

   (ii) Vapours from 1st body of preevaporator used for 'C' boiling and for final heating of treated juice.

   (iii) Vapours from 2nd body of preevaporator used for 'A' and 'B' boilings and for partial heating of treated juice, to 95°C.

   (iv) Vapours from 2nd body quadruple for raw-juice heater.

2.(a) Conditions in preevaporator

   (i) Calandria 1st body
   (ii) Vapour space 1st body
   (iii) Vapour space 2nd body

   Pressure
   0.7 kg/cm²
   0.48 kg/cm²
   0.3 kg/cm²

(b) Temperature of boiling juice in 1st body 112.4°C.

3. (i) Vapour from preevaporator body 2 for treated juice heating—

   \[ \frac{100 \times 1000 \times 0.9 (95 - 65)}{0.95 \times 534 \times 1} = 5.32 \text{ t.} \]

(ii) Vapour from preevaporator body 1 for final heating of treated juice

   \[ \frac{100 \times 1000 \times 0.9 (102 - 95)}{0.95 \times 531 \times 8} = 1.25 \text{ t.} \]
(iii) Steam for clear juice heating

\[
\text{Steam} = \frac{100 \times 1000 \times 0.9 \times (112 \times 4 - 95)}{0.95 \times 528 \times 9} = 3.12 \text{ t.}
\]

4. (i) Total evaporator in preevaporator

2nd body \(15 + 5.32 = 20.32 \text{ t.}\)

1st body \(20.32 + 1.25 + 7.00 = 28.57 \text{ t.}\)

\[\therefore \text{Steam to preevaporator} = 28.57 \text{ t.}\]

(ii) Total steam \(0.7 \text{ kg/cm}^2\) =

(i) Preevaporator \(= 28.57 \text{ t.}\)

(ii) Clear-juice heating \(= 3.12 \text{ t.}\)

Total \(31.69 \text{ t.}\)

5. \(0.5 \text{ kg/cm}^2\) (i) Quadruple Evaporation = \(75 - 20.32 - 28.57 = 26.11 \text{ t.}\)

\[
\text{Steam} = \frac{26 \times 11 + 6 \times 13 \times 2}{4} = 9.59 \text{ t.}
\]

Vapours to condensor = \(9.59 - 6.13 = 3.46 \text{ t.}\)

6. Total steam required—

(i) \(0.7 \text{ kg/cm}^2\) \(= 31.69 \text{ t.}\)

(ii) \(0.5 \text{ kg/cm}^2 = 9.59 + 5\) \(= 14.59 \text{ t.}\)

7. Total heat consumption\( = 16,760.8 \times 10^3 \text{ K cal}\)

\[+ 7,754.4 \times 10^3 \text{ K cal}\]

Total \(24,515.2 \times 10^3 \text{ K cal}\)

6. COMMENTS ON THE DIFFERENT SYSTEMS OF VAPOUR BLEEDING

The foregoing calculations do not take into account finer points relating to steam economy due to utilisation of condensate flash etc. but serve to highlight the benefits obtained with use of vapour bleeding arrangements in accordance with the well known Rillieux principles. Purely from the steam economy angle the rating of different systems covered by these calculations is as under—

(i) Double effect preevaporator and quadruple \(\text{Case 9}\)

(ii) Quintuple and vapour cell \(\text{Case 8}\)

(iii) Quintuple with vapour bleeding as in \(\text{Case 7}\)
The adoption of a particular system by a plant will be dictated mainly by the size of the plant, the total production of sugar per annum and the following points need to be borne in mind in connection with the choice of vapour bleeding system:

(a) Greater use of vapour for pan boiling and juice heating undoubtedly leads to high degree of energy conservation in as much as steam consumption in process is reduced and the load on condenser is brought down. For generation of adequate amount of vapour, the heating surfaces of different vessels have to be carefully worked out. The evaporator system design has to be based on the vapour utilisation for different stations.

(b) The heating surfaces have to be cleaned before heavy scale retards the rate of generation of sufficient vapours. This is particularly important in the case of preevaporator in areas where scale formation is high.

(c) Sucrose decomposition accompanied by destruction of reducing sugars is occasioned by a combination of three factors viz. (i) pH (ii) time (iii) temperature. It is important that the decomposition of both sucrose and reducing sugars is avoided or minimised in the evaporator and in this connection undermentioned precautions are essential—

(i) The pH of juice is lowered at higher temperature prevailing in the evaporator first body or pre-evaporator by 0.2 to 0.4

(ii) The retention of juice in the preevaporator or first body has to be minimum.

(iii) The temperatures of pressures adopted in the first vessel or vapour cell have to be chosen keeping in view the effect on decomposition of sugars.

The retention of juice in evaporator vessel depends on the total volume of juice boiling in the vessel and can be determined from the throughput of juice, brix of juice together with the volume as under.

\[
\text{Retention time} = \frac{\text{Average brix of juice in vessel} \times \text{volume of juice in litres} \times \text{sp. gr.}}{\text{kg brix of clear-juice per minute}}
\]

It needs to be emphasised that in sugar producing unit the steam economy is not to be achieved at the expense of recoverable sugar and careful watch is necessary for avoiding sugar loss in the evaporator system. Inversion of sucrose and destruction of reducing sugars have been reported from some factories which have installed double effect preevaporator. Each factory has to determine the possible effect of pressures and temperatures of steam on the sugars and adjust the working conditions accordingly.
(d) Design of Pre-evaporator or first vessel plays a significant role in respect of retention of juice and falling film evaporator bodies might be most suitable from this angle.

(e) For effective vapour bleeding particularly for pans, smooth operation with constant and regulated steam supply, constant juice feed and vacuum conditions are absolutely essential.

7. PERFORMANCE OF INDIVIDUAL BODIES OF EVAPORATOR

Study of the evaporator performance on the basis of observed conditions of pressures, employing the Dessin formula $C = 0.001 \times (100 - B) \times (T - 54)$ helps understand the efficiency levels of different bodies of the station. The following calculations are based on certain assumptions viz.

(i) 100 t. juice per hour to be evaporated in quadruple

(ii) 3rd body vapours used for raw-juice heating (35° - 70°)

(iii) 1st body vapours used for sulphured juice-heating from 65°C to 92°C

(iv) Heating surfaces of bodies—

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>800 m²</td>
</tr>
<tr>
<td>2nd</td>
<td>700 m²</td>
</tr>
<tr>
<td>3rd</td>
<td>700 m²</td>
</tr>
<tr>
<td>4th</td>
<td>700 m²</td>
</tr>
</tbody>
</table>

(v) Conditions in evaporator as under—

(a) Steam to 1st body at 0.5 kg/cm² and 112°C.

(b) Vacuum in the last body 635 mm.

(c) Temperatures observed together with real temperature drop are as in the Table below—

<table>
<thead>
<tr>
<th></th>
<th>Temperature of Vapour side</th>
<th>Temp. °C Juice</th>
<th>B.P.E. °C</th>
<th>True Temp. difference °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Body Calandria</td>
<td>112°C</td>
<td>102.7</td>
<td>1.6</td>
<td>7.7</td>
</tr>
<tr>
<td>2nd Body Calandria</td>
<td>102.7°C</td>
<td>93.0</td>
<td>1.85</td>
<td>7.85</td>
</tr>
<tr>
<td>3rd Body Calandria</td>
<td>93.0°C</td>
<td>79.5</td>
<td>2.8</td>
<td>10.7</td>
</tr>
<tr>
<td>4th Body Calandria</td>
<td>79.5°C</td>
<td>56.3</td>
<td>5.8</td>
<td>17.4</td>
</tr>
</tbody>
</table>
Evaporation in different Bodies—

1st — 23,823.9 kgs  
2nd — 19,062.4 kgs  
3rd — 19,062.4 kgs  
4th — 13,051.2 kgs

Brixes of juices leaving different bodies—

1st body \( x_1 \times 76176.1 = 15 \times 100000 \)
\[ x_1 = 19.69 \]

2nd body \( x_2 \times 57113.7 = 15 \times 100000 \)
\[ x_2 = 26.26 \]

3rd body \( x_3 \times 38,051.3 \)
\[ x_3 = 39.42 \]

4th body \( x_4 \times 25000 = 15 \times 100000 \)
\[ x_4 = 60 \]

Total evaporation = \( 60 \times \frac{15}{60} \times 1,00,000 \)
\[ = 75,000 \text{ kgs.} \]

Vapour for raw-juice from 3rd body
\[ = 0.9 \times 100 \times 1000 \times (70-35) = 6011.2 \text{ kg.} \]

Vapours for sulphured juice heating from 1st body
\[ = 0.9 \times 100 \times 1000 \times (92-65) = 4761.5 \text{ kg} \]
\[ 0.95 \times 537.2 \]

Evaporation in each body

4th body — \( x \)

3rd body — \( x + 6011.2 \)

2nd body — \( x + 6011.2 \)

1st body — \( x + 6011.2 + 4761.5 \)

i.e. \( 4x + 18,033.6 + 4761.5 = 75,000 \)

\[ \therefore x = \frac{75000 - 18,033.6 - 4761.5}{4} = 130,51.2 \]
Average brixes—

1st body — 17.34
2nd body — 22.98
3rd body — 32.84
4th body — 49.71

Efficiency of operation of a body is arrived at from the Dessin formula

\[ C = 0.001 (100 - B)(T - 54) \]

Where \( B \) = Average brix in the vessel and
\( T \) = Temperature of heating vapour.

Efficiency = \( \frac{E_n}{C \times T \times S} \)

\( E_n \) = Evaporation in body no. \( n \) in kg.
\( C \) = Specific evaporation coefficient \( \text{kg/m}^2/\text{hr/°C} \)
\( T \) = Net temperature drop from heating vapour to juice °C
\( S \) = Heating surface in m²

1st body Efficiency = \( \frac{23,823 \cdot 9}{0 \cdot 001(82 \cdot 66 \times 58 \cdot 0 \times 7 \times 7 \times 800)} = 0.81 \)

2nd body Efficiency = \( \frac{19062 \cdot 4}{0 \cdot 001(77 \cdot 02 \times 48 \cdot 7 \times 7 \times 85 \times 700)} = 0.92 \)

3rd body Efficiency = \( \frac{19062 \cdot 4}{0 \cdot 001(67 \cdot 16 \times 39 \cdot 0 \times 10 \cdot 7 \times 700)} = 0.97 \)

4th body Efficiency = \( \frac{13051 \cdot 2}{0 \cdot 001(50 \cdot 29 \times 25 \cdot 5 \times 17 \cdot 4 \times 700)} = 0.83 \)
REFERENCES


Fig. 1.
B W FORCED FLOW
EVAPORATOR BODY

Fig. 2.
Semi Kestner body

Fig. 3.
KESTNER EVAPORATOR

Fig. 4.
F F. EVAPORATOR

Fig. 5.
Fig. 6. Centrifugal Catchall
ENTRAINMENT CATCHERS 'INTERNAL'

TYPE - 1

HELMET

UMBRELLA TYPE

CENTRIFUGAL TYPE

Fig. 7.
Fig. 8.

THERMO-COMPRESSOR

Fig. 9.

TURBO COMPRESSOR
ARRANGEMENT OF EVAPORATION & HEATING
DEVIC & QUAD

Fig. 10.
6. SYRUP TREATMENT

1. As stated earlier, the syrup from evaporator contains good amount of suspended matter (0.3 - 0.5% Bx) nearly four to five times that in clear juice on 100 brix basis. Since in the production of plantation white sugar, sugar crystals are grown in syrup, some of the suspended matter in syrup gets embedded in sugar crystals and an ideal way would be to treat the syrup further with chemicals followed by filtration for elimination of suspended matter as also colour forming components. Filtration of syrup requires the brix of syrup to be lowered to 50 or so and addition of filter aid like Kieselguhr but this procedure works out to be uneconomical from the point of view of steam economy and the proportionate gains.

In a process introduced by Perk the concentrated juice from penultimate body of quintuple was treated by sulphitation followed by filtration. The clear syrup was sent to the last body of evaporator for further concentration. Similar principle of operation has been adopted in middle juice carbonation. However in the present context it is important to deal with syrup from evaporator for clarification.

A new method introduced in recent years for syrup treatment which is practised in some plants in white sugar manufacture is the Tolodura process based on phosfloatation principle involving treatment of syrup with chemicals.

2. CHEMICAL TREATMENT

(a) In Tolodura process developed by Tate & Lyle the heated syrup is treated with lime and phosphoric acid and the syrup with precipitate of tricalcium phosphate goes to aeration tank where finely divided air is injected into it. This is followed by mixing with the aerated syrup a special flocculating agent 'Talodura' before its entry into a floatation clarifier. The principle of this treatment is almost the same as phosfloatation of melt in refineries.

(b) Satisfactory results have been reported from Kiccha Sugar Co., by treatment of syrups and melt of 'C double cured and 'B' single cured sugar by phosfloatation employing polyacrylamide flocculant.

The above phosfloatation process involves installation of extra equipments like clarifier, reaction tank and aeration equipment and this calls for extra capital expenditure, as also the extra expenditure on chemicals. However, the introduction of this process definitely gives benefits in the form of

(i) improvement of sugar quality
(ii) reduction of viscosity and
(iii) better performance of low grade boiling and exhaustion by eliminating the suspended impurities, turbidity and bring down the colour content.

3. SYRUP SULPHITATION

3.1. Sulphitation of syrup from evaporator which is at 6.5 to 6.6 pH is a common practice in white sugar manufacture. The common procedure in plantation white sugar manufacture is to blow sulphur dioxide in the syrup in a special tank till it reaches pH of 5.2 to 5.4 from where it is pumped to pan floor supply tanks. The sulphur dioxide has a bleaching action on syrup and the sulphitation of syrup assists the crystallisation process in three ways—

(i) SO₂ reacts with organic acid compounds of calcium to form calcium sulphites releasing free organic acids.

(ii) SO₂ reduces the ferric ions to ferrous ions and thereby prevents development of dark coloured compounds, resulting from the reaction of ferric compounds with polyphenols.

(iii) According to Zerban SO₂ most probably blocks the carbonyl group of reducing sugars, thereby checking the caramel and melanoidin formation, the reactions leading to development of colour.⁵

Out of the SO₂ absorbed by the syrup a major portion finds its way to molasses while the white sugar contains about 20-30 p.p.m. of SO₂. Excessive sulphuring of syrup below 5.2 pH serves no purpose but on the contrary exerts adverse effects in two ways—

(i) good amount of SO₂ escapes along with vapour in 'A' massecuite boiling leading to corrosion of pan vapour pipes.

(ii) low pH of syrup results in inversion of sucrose as shown by the work of D.P. Kulkarni and others and under no circumstances should syrup pH be lowered below 5.2 during sulphitation.⁶

3.2. Equipment—Continuous syrup sulphitation has almost completely replaced batch system and the total equipment for this station includes

(a) syrup sulphitation tank,

(b) sulphited syrup receiving tank with pump,

(c) continuous sulphur burner.

Syrup sulphitation tank is of M.S. construction, having a conical bottom and syrup outlet is provided through a siphon arrangement. The height of the siphon of about 1.5 m. enables sufficient time of contact of syrup with SO₂ gas. Uniform distribution of gas in the tank is important and distributor and baffles are provided for this purpose. The SO₂ inlet is connected at the bottom of the cylindrical tank, with suitable valve to regulate the flow of gas. The syrup enters a tower mounted over the top of tank. The gas escaping the syrup passes through the tower which is fitted with suitable baffles and thus is partially absorbed by the fresh incoming syrup. This syrup inlet in the tower thus reduces to an extent SO₂ content of the exhaust gas from the sulphitation vessel.
3.3. In most of the factories syrup sulphitation is manually controlled. The variations in pH of sulphited syrup occur mostly on account of

(i) uneven flow of incoming syrup.

(ii) fluctuations in \( \text{SO}_2 \) gas supply.

There are three ways to control the pH of sulphited syrup automatically which are described in brief below—

(i) pH sensor at the outlet of syrup from the sulphitation tank sends signals to a controller which regulates the \( \text{SO}_2 \) generation in the sulphur burner.

(ii) pH measured at the outlet of tank regulates the \( \text{SO}_2 \) relief valve fitted on a branch pipe connected to the \( \text{SO}_2 \) line before the \( \text{SO}_2 \) valve of the tank. The other end of branch pipe is connected to the \( \text{SO}_2 \) tower of the sulphitation tank. Thus when the pH limits are set between 5.2 - 5.4, lower pH will force more \( \text{SO}_2 \) to escape through the relief valve, into the tower while above the upper set point of pH the relief valve will be completely closed. This way the pH sensor will transmit instructions to controller for regulating the relief valve.

(iii) \( \text{SO}_2 \) gas supply to tank is regulated in the same way as above but an additional arrangement to regulate supply of syrup from evaporator is provided by installing a buffer tank for syrup from evaporator, from which syrup is pumped into the sulphitor. The buffer tank has a level control arrangement linked to the pH sensor. When the pH is low more syrup is pumped into sulphiter while if the pH goes up the syrup feed is reduced by recirculating part of untreated syrup from buffer tank through a special branch line of the main delivery pipe of the pump. In this branch line is fitted a valve the opening of which is controlled by the signal from pH sensor. The level of the buffer tank which has a total hold up of 15-40 minutes, can thus be controlled automatically within certain safe limits depending on the pH of sulphured syrup.

Irrespective of the mode of control, the pH must not fall below 5.0 nor exceed 5.6, the optimum being 5.2 - 5.4. Needless to state that maximum sulphur economy can be achieved in this operation only by maintenance of optimum pH and by minimising the quantity of unabsorbed \( \text{SO}_2 \) gas let out through the tank into atmosphere. A separate sulphur burner for syrup sulphiter is desirable with maximum capacity of burning 0.03% sulphur on cane. In most of the new plants the syrup sulphitor is located alongside the juice sulphitation tanks i.e. on the first floor while the sulphur burner along with compressor are installed on ground floor, whereas some plant manufacturers prefer to have the syrup sulphitor along with sulphur burner and compressor on pan floor to avoid pumping of sulphited syrup which sometimes presents problems due to foam generated in syrup.

4. SYRUP BLEACHING BY HYDROGEN PEROXIDE

Hydrogen peroxide is an oxidising agent and reacts with organic and inorganic
compounds by releasing oxygen following the reaction $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$. Dilute solutions are to be used for bleaching organic matter. Hydrogen peroxide reduces colourant in syrup by attacking the colour forming compounds like polyphenols. Its successful use for decolouring syrup was established for the first time on factory scale trial at Ugar Sugar Works Ugar Khurd in Deccan. In replacement of the method of sulphitation, syrup from evaporator was treated with 1% hydrogen peroxide the level of hydrogen peroxide being maintained at 20 p.p.m. Addition of peroxide in replacement of sulphitation has resulted in reduction in sugar colour by 46%.

(i) 20% reduction in sulphated ash and

(ii) lowering the $\text{SO}_2$ content of final white sugar by 50%.

The economics of this process as presented by Mantri and others is favourable for its adoption. The ideal method would be to add the predetermined dose of peroxide to syrup in a tank equipped with efficient stirring arrangement. The time of contact has to be determined by experimentation. Though this chemical is used as oxidising agent it acts as a reducing agent also when reacted with more powerful oxidising agents like $\text{KMnO}_4$, $\text{AgNO}_3$ etc.

More scientific data is required to be collected to understand the reactions that take place as a result of addition of hydrogen peroxide particularly with respect to effects on levulose and glucose during pan boiling as also the various colourants. The process however holds good promise of replacing the existing sulphitation system. The obvious advantages of this method over the existing sulphitation are that—

(1) $\text{H}_2\text{O}_2$ is a harmless chemical to handle and involves no evolution of harmful gas like $\text{SO}_2$.

(2) The resulting sugar from $\text{H}_2\text{O}_2$ treatment is bound to contain much less $\text{SO}_2$, which might render it suitable for food processing, pharmaceutical and other industries like fruit canning wherein sulphite content in sugar is considered undesirable.

It is not advisable to practise sulphitation of syrup and then use hydrogen peroxide in the 'A' pans in view of its property to oxidise sulphites to sulphates according to equation

$$\text{H}_2\text{SO}_3 + \text{H}_2\text{O}_2 \rightarrow \text{H}_2\text{SO}_4 + \text{H}_2\text{O}.$$
REFERENCES

8. Ibid.
PART-I

SUGAR CRYSTALLISATION

1. The process of sugar manufacture essentially consists in isolating sucrose crystals from water as well as the impurities and therefore crystallisation of sugar is the heart of the process operation. In the major process of production of sugar from cane or beet viz., (a) sugar from cane by open pan boiling system, (b) plantation white sugar manufacture from cane and (c) white sugar from sugar beet practised in our country the system of crystallisation has the most important place. It is at the crystallisation that the 50-60% of the total loss in manufacture takes place and fate of the quality of marketable sugar is decided. Even in the refinery operations, involving raw sugar of 97.99% purity crystallisation station plays the most important role in entire process of manufacture, in as much as this constitutes the final stage of removal of most of the impurities contained in the raw material as in the production of sugar from cane or beet.

The syrup sent to pan floor is of 55°-65° Bx, the upper limit being rarely crossed. The entire process of crystallisation on panfloor is conducted in three or four stages, the mother liquor from the final stage being discarded as final molasses. The feed material of the pans at second and later stages of boiling is of about 70° Bx. For recovering maximum sugar in crystalline form high concentration of the massecuites under vacuum is essential consistent with the requirements of discharging the mass from the pans. The brixes of first grade massecuites i.e. 'A' strikes from which white sugar is produced are 92-94 while the final massecuites, whose mother liquor when separated is the final molasses are concentrated to 100°-102° Bx. Concentrating beyond certain limits at any stage can cause unwanted secondary grain formation or conglomerates besides affecting the fluidity of the massecuites.

2. FUNDAMENTAL ASPECTS

2.1. The white sugar produced for human consumption contains 99.9% sucrose. It is therefore pertinent to examine the physical properties of sucrose in the context of the crystallisation process followed in the process of mill-white sugar manufacture. Since we have to deal with syrups and molasses which contain nearly 15-50% non-sucrose matter on brix basis it is equally important to consider the influence of nonsucrose impurities on the physical properties of sucrose and also on the crystallisation of sugar. Unlike in the refined sugar
manufacture where sugar is crystallised out from purified sugar liquors, the plantation white sugar process involves use of syrups whose composition of impurities varies widely in different parts of the season.

2.2. Solubility of sucrose—If we go on adding sucrose to water a stage is reached when no more solid sucrose will go into solution, when the solution is considered to be saturated. Sugar is highly soluble in water and the solubility increases with temperature. Tables of solubility of sucrose at various temperatures ranging from 0 to 100°C have been prepared on the basis of data collected by different investigators, prominent amongst them being Hertzfeld\(^1\) and the relation between sucrose in saturated solutions at different temperatures is given by the following equation:

\[
C = 64.18 + 0.1348t + 0.000531t^2
\]

Where \(C\) = sucrose in saturated solution at temperature \(t^\circ C\) Subsequent investigations by Charles, Vavrinecz and others who obtained deviations from these according to Hertzfeld table led ICUMSA to review the solubility data and finally ICUMSA has officially accepted the tables of Vavrinecz and Charles. Accordingly the equation for solubility of sucrose from 0\(^°\) to 90\(^°\)C is\(^2\)

\[
S = 64.397 + 0.07251 t + 0.002069 t^2 - 9.035 \times 10^{-6} t^3
\]

Where \(S\) = Solubility and \(t\) the temperature.

2.3. Effect of non-sucrose components—As in white sugar manufacture we are dealing with impure sucrose solutions like syrup, it is essential to understand the influence of impurities on the solubilities of sucrose. Considerable work has been reported on the solubility of sucrose in the presence of impurities both organic and inorganic, which can be briefly stated as under:

(a) Sucrose solubility diminishes in the presence of reducing sugars.

(b) Inorganic solutes in general increase the solubility of sucrose—particularly the chlorides of potassium and sodium at high temperature.

Solubility of sucrose in the presence of impurities in syrup or molasses is expressed in terms, of parts of sucrose per 100 parts of water. The term solubility coefficient used in this context is expressed as—

\[
S = \frac{\text{Sucrose/100 water at Saturation of solution of impure solution at temp. } t^\circ}{\text{Sucrose/100 water at saturation of sucrose solution at temp. } t^\circ}
\]

The term saturation coefficient is used in some literature to indicate the solubility of sucrose in impure solution in relation to solubility of pure sucrose but has now been replaced by the term 'solubility coefficient' while the solubility of sucrose is referred to as 'solubility number. Graphs have been drawn on the basis of comprehensive data on solubility coefficients at different levels of impurities which provide relationships between the purity, temperature and dry substances of the saturated solution.
2.4. Super Saturation—When a saturated sucrose solution is cooled or when its water is evaporated in such a way that no sugar crystals are formed the solution is said to be supersaturated since it contains more sucrose than a saturated solution, the degree of supersaturation also known as coefficient of supersaturation is arrived at from the equation:

\[ S = \frac{\text{sucrose to water ratio at temperature } t^{\circ} \text{ in a supersaturated solution}}{\text{sucrose to water ratio at temperature } t^{\circ} \text{ in a saturated solution}} \]

In the process of sugar manufacture we have to deal with impure sugar solution in which the solubility of sugar is higher than in pure sucrose solutions and the coefficient of supersaturation is always higher as the purities of solution become lower and the coefficient of supersaturation is arrived at from—

\[ \text{ratio of sugar to water at temperature } t^{\circ} \text{ C of impure solution} \]
\[ \text{ratio of sugar to water at temperature } t^{\circ} \text{ C and same true purity in saturated solution} \]

Supersaturation being the main driving force in the crystallisation, the degree of supersaturation of mother liquor in boiling pans determines the rate of crystal growth.

2.5. B.P.R.—Boiling point rise or boiling point elevation (B.P.R.) is the rise in boiling temperature of concentrated syrup or molasses over that of pure water at the same pressure or vacuum. Some general rules relating to B.P.R. which have relevance to the conduct of pan-boiling in cane sugar manufacture are—

(a) The B.P.R. increases with concentration or brix of boiling solution

(b) B.P.R. increases as purity of boiling solution decreases.

(c) B.P.R. decreases with temperature.

Thus purity and temperature remaining the same the B.P.R. would be proportionate to the dissolved solids per 100 parts of water. In a boiling solution the B.P.R. is given by the difference in the temperature of the boiling solution and the vapours leaving. Since B.P.R. of a boiling solution is directly proportional to the concentration of dissolved solids, it is possible to know the coefficient of supersaturation of a particular boiling solution from the boiling point rise of the supersaturated and saturated solutions of the same temperature. In this way the supersaturation is given by the relation.

\[ S.C. = \frac{\text{B.P.R. of boiling solution}}{\text{B.P.R. of saturated solution at the same temperature}} \]

The above formula requires determination of boiling point elevation at saturation for different temperatures and purities of sugar solution dealt with in the pan boiling. Moreover, the B.P.R. at saturation is influenced not only by the amount of impurities but also the composition of nonsugar component. But once the relationship between the boiling point rise at saturation is established at different temperatures for a particular composition of nonsugars in a material it is easy to find out the supersaturation. Graphs based on Holven's data of boiling point elevation at saturation for different purities of massécuites throw light on the variations in saturation temperature of mother liquor of
boiling massecuite with massecuite temperatures and purities. Instruments have been developed to control pan boiling making use of measurements of boiling point elevation of massecuites.

2.6. Specific heat—the specific heat of sugar solutions of different concentrations has been determined and is represented by the equation \( C = 1 - 0.006 \) B., where B denotes brix of sugar solution. For heavy massecuites the specific heat value can be calculated by the formula \( C = 1-0.007 \) B. According to Hugot, for intermediate brixes the values will be between those given by these two formulae.\(^4\)

3.0. CRYSTAL GROWTH

3.1. No sugar crystals can form or develop in a sugar solution unless the solution is supersaturated. The state of supersaturation signifies more solute in solution than that contained in a saturated solution and saturated solution is one in which no more solute can go into solution at a particular temperature. Supersaturation curves showing relationship between sucrose concentration and temperature show three zones viz.,

1. Metastable zone of supersaturation coefficient 1 to 1.20 in which existing crystals grow but new crystals are not formed.
2. Intermediate zone with S.C. 1.2 - 1.4 represents a phase in which existing crystals grow and new ones are also formed.
3. In Labile Zone of supersaturation coefficient exceeding 1.4 spontaneous nucleation of sucrose will take place.

For practical pan boiling the useful range of supersaturation is 1.25 to 1.4 depending on the grade or stage of boiling.

As stated earlier, with lower purities of solutions the degree of supersaturation has to be higher for crystallisation.

3.2. Crystal growth mechanism—The sugar crystal growth in a supersaturated sugar solution takes place as a result of two processes. One: transfer of sucrose molecules from the bulk of solution to the surface of crystal, two: incorporation of these molecules in the crystal lattice. The crystal growth depends on these two reactions and the rate is determined by the slower process. In the case of a sucrose crystal suspended in a supersaturated sugar solution sucrose molecules from the bulk of solution will be transported to the crystal face by diffusion as the film near the face of crystal will be thin. As the sucrose molecules get deposited in the crystal lattice, the film near the crystal has a lower degree of supersaturation than the bulk of solution, due to reduction in concentration of solute as also due to the effect of heat of crystallisation. The supersaturation is the main driving force which increases the rate of diffusion of sucrose molecules to the crystal surface and thus the role of growth of crystals will be determined mainly by the degree of supersaturation of the sugar solution. In the light of various investigations Van Hook states that out of the two steps in the mechanism of crystal growth viz. the diffusion of sucrose molecules to the face of crystals and the accommodation in the crystal lattice, the
former i.e. the transport or diffusion is less important at low temperature, but at 50°C both these processes have the same rate. Thus viscosity will not impede the crystal growth since the diffusion is not the main dominant factor in the growth of sugar crystals.

The rate of crystallisation in pure and impure sugar solutions like molasses increases with temperature at high degree of supersaturation. Similarly at the same temperature crystallisation rate is higher, higher the supersaturation.

3.3. Effect of impurities—The nonsucrose impurities in syrups or molasses exert adverse influence on the crystallisation rate. Besides the concentration of impurities the composition and nature of impurities decide the rate of crystallisation. Electrolytes in general have retarding effect on rate and similarly caramel and carbohydrates considerably slow down the crystallisation. This is in accord with the slow rate of crystal growth in low purity massecuite. Smythe's studies on growth of sugar in pure and impure solution have shown that the impurities fall into two categories. Those that increase viscosity and retard the mass transfer of sucrose molecules to crystals and secondly those that hamper the crystal growth by obstructing the incorporation of sucrose molecules in crystal. The former group includes electrolytes, reducing sugars and number of organic compounds while in the second category are oligosaccharides.

Studies conducted by Smythe have thrown light on the retarding influence of small concentrations of raffinose, and Kestose on the growth rate of sugar crystals as they are adsorbed on the growing sugar crystals. In this connection the different oligosaccharides have been found to exert effect on growth rate by adsorption to a varying degree and they get preferentially adsorbed on different faces depending on their structures. Raffinose and dextran are known to cause habit modification of sugar crystals resulting in formation of acicular or elongated sugar crystals. In factories processing stale cane the phenomenon of elongation of sugar crystals is often noticed due to the presence of dextran formed in cane juice as a result of bacterial infection during the long delay between harvest and processing. The elongation of crystals results from preferential adsorption of dextran on the growing sugar crystals. In general both inorganic and organic impurities slow down the rate of crystal growth and some like caramel get adsorbed on the growing sugar crystals and are bound throughout the crystal. Likewise platelet formation is also occasionally observed in boiling, which is ascribed to retardation of growth along one axis, while at times needle shaped crystals are obtained in low grade boilings. These crystal habit modifications are caused by impurities in the medium.

4. PRACTICAL ASPECTS

4.1. In practice the above principles of growth of sucrose crystals are employed in pan boiling operation. The process of crystallisation is carried out in 3 or 4 stages, the impurity content in mother liquor progressively increasing from the first to the last stage. As purities of mother liquor i.e. molasses decrease, the degree of supersaturation increases for boiling and in the final stage of crystallisation the supersaturation coefficient is 1.5 or
above and thus gradual desugarisation of the syrup sent to pan floor is achieved by adopting 3 or 4 boiling systems.

4.2. False grain—In pan boiling once seed is drawn in the pan no new grains are allowed to be formed which means that no new nucleation should occur since the grains provided by the seed have to be developed, which requires the concentration of mass to be so controlled as to avoid the labile or intermediate zone maintaining the state of supersaturation in the metastable zone. In practice at certain stage of boiling the concentration of the massecuite exceeds a certain limit when fresh grains appear as tiny crystals known as false grains. If allowed to grow the false grain will constitute another crop of crystals of smaller size rendering the massecuite full of different sized crystals which retard the passage of molasses through the crystals in centrifugal separation thereby giving poor quality sugar. In pan boiling when a strike concentration overshoots the mark, initially a hazy mass appears which if not dissolved quickly gives rise to innumerable tiny crystals. Under such conditions, the pan boiler has to get rid of the false grain by bringing down the saturation which is done by giving drinks of water and raising the temperature. This procedure though helpful in dissolving the secondary grain however partly dissolves the original well formed crystals of the strike. In a pan well advanced in boiling, this step results in loss of time, spoiling the crystal shape and exerts adverse effect on desugarisation of mother liquor referred to usually as exhaustion. Thus it is absolutely essential to prevent formation of secondary grain in boiling.

4.3. Conglomerates—These are crystals joined together at some stage of boiling pan and can be noticed even in the white sugar appearing in market. In the early stages of boiling a strike many times two or more crystals join together throughout the massecuite and further grow to form conglomerates some times known as rolled grain. Apart from imparting bad appearance to the sugar crystals they are objectionable for two reasons, one—the joined grains contain impurities of mother liquor at the interface known as inclusions and second—they impede the proper washing in centrifugal separation, thereby affecting adversely the quality of sugar. The conglomerate formation normally is observed in pans with poor circulation characteristics with some pockets having poor displacement of mass during boiling. Installation of mechanical circulator in a pan improves the situation by stirring the boiling massecuite and bringing about better circulation even at high brix of the massecuite. Conglomerates are formed mostly in high purity massecuites in the top area of metastable zone prior to false grain formation. Thus high concentration beyond a certain limit in the metastable zone and poor circulation of massecuites in some pockets induce conglomerate formation in high grade boiling.

4.4. Crystal Size—Rate of crystallisation is directly proportional to the area of crystals in a mother liquor and thus under identical conditions of purity, supersaturation and other boiling conditions the massecuite with smaller crystals will give mother liquor of lower purity then the one with bigger crystal size. Greater area for deposition of sucrose is available when the crystal size is reduced and area of crystal surface is given by the equation—

$$S = \frac{0.00421}{d}$$

where $S$ = surface area in m$^2$/gm

and $d$ = length of crystals in mm.
In panboiling operation the crystal length of about 1.0 mm in white sugar boiling is brought down to 0.2 mm. in final massecuite where maximum exhaustion of mother liquor with very high impurity content is aimed at.

5. PAN STATION

5.1. The pan station of a sugar factory is located on separate floor either in line with the evaporator station at a height of 7-8 m. from ground floor or at a height of 15-16 m. from ground floor so as to facilitate gravity flow of massecuites from pans upto centrifugal station. Pan station is equipped with 4 to 8 pans of capacities varying from 50 to 60 t. together with 15-20 syrup and molasses tanks and seed crystallisers for storing seed for high grade boiling. Besides these, vacuum crystallisers are also installed now a days for storing 'cutting' from pans. The entire boiling is conducted under vacuum and therefore the pans are connected to condensers by large vapour pipes. The various important pipe connections of a pan include—

(i) steam or vapour,
(ii) syrup and molasses,
(iii) seed intake or cut over pipe,
(iv) condensate outlet,
(v) vapour outlet,
(vi) hot water,
(vii) gauges and meters.

5.2. Types of pans—Pan boiling has so far been a batch operation but in the last two decades continuous pans have been introduced. In Indian industry gradually continuous pans will take the place of batch pans in the near future particularly for intermediate grade boilings. The batch pans can be broadly classified into two types

(i) coil pans,
(ii) calandria pans.

Whatever the design or type of pan it is necessarily fitted with following accessories—

(a) a condensor connected to vapour pipe, either barometric type or a multi-jet one.
(b) Catchall at the top before the vapour pipe to prevent entrainment or carryover.
(c) A vacuum breaking valve to be used before dropping a strike.
(d) Sight glasses on the front as well as at the back.
(e) Manhole door.
(f) Large discharge valve.
(g) Pan washing arrangement.

Besides above the various pipe connections are provided with appropriate valves.
5.3. Coil pan—The sugar plants established in the thirties or even prior to 1930 were provided with coil pans. In the old design, coils were of copper tubes bent into spirals with the upper end connected to the wall of the pan while the other one i.e. the lower one is joined to the condensate-drain. The coil is wound in such a way as to facilitate easy drainage of condensate. A set of coils is installed, each one being connected to steam line through valve and steam trap to enable independent start or cutout of any one coil. The successive coils are so laid as to aid circulation of massecuite in the pan. The pan body can be of MS. or cast iron. The coils are made of 10-15 cm. dia copper tubes with wall thickness of about 2.5 - 4 mm. The ratio of length to diameter of coil is 200-250 for live steam, but for using exhaust steam it has to be 75-100. The pan is equipped with usual fittings like sight glasses for observing levels of massecuite, catch all etc.

Pan with flattened coils—In a new design of coil pan introduced in Queensland the flattened coils form the heating surface. The coil constructed of 12.5 cm. dia. copper tube is flattened so as to give nearly 1½ times or double the height over the width. The coil consists of concentric flattened tubes with two ends connected to steam manifold and condensate outlet respectively. The only advantage of the coil pans is that the heating surface is gradually cut in or brought into operation as the strike level rises but the main disadvantages are—

(a) high maintenance costs,

(b) use of vapours or low pressure exhaust is not possible as mostly live steam is required for boiling.

(c) mechanical circulator cannot be installed.

In recent past for the above reasons coil pans have completely been replaced by calandria pans.

5.4. Calandria pans—

5.4.1. Like an evaporator body a calandria pan has tubular calandria with the difference that the tubes are of larger diameter and shorter length as also larger downtake to facilitate circulation of high brix material. Circulation of thick massecuite is of utmost importance in the design of calandria and this is brought about by providing large down-take for the ascendings stream of mass through the tubes. As a result of heat transfer from the steam or vapour to the massecuite it rises in the tubes and on reaching the top of upper tube plate descends through the down take. This efficiency and speed of circulation of mass is an important characteristic of any calandria pan design.

5.4.2. In a conventional design of 30m³ capacity pan, the calandria is fitted with 100 mm. O.D. and 96 mm I.D. brass tubes of 1.1 m. length, with end portions expanded and fixed in two plates of 25 mm. thickness with a ligament of 16 mm. In the calandria of M.S. construction the downtake is provided with deflector of fanned shape at an angle of 45° at the upper end of the downtake opening to prevent short circuiting of massecuite flow. Usually one steam connection is provided and the condensates drained from the opposite side into a tank located on ground floor. The shell of pan body is of 12 mm. M.S. construction and has an internal catchall in the top dome which is connected to vapour
pipe going to condenser. The conical bottom is bolted to the calandria or even welded in some case and the pan discharge valve is located in the centre. The feed is connected to the bottom cone away from the discharge valve but in some designs the feed enters the pan in the downtake. A cut over line is connected to the bottoms of all pans and seed or vacuum crystalliser. The conical bottom of each pan is joined to the cutover line through an opening and valve. The diameter of central cylindrical down take is 40-50% of that of the calandria.

The heating surface to volume ratio has to be 6-6.5 m\(^2\) per m\(^3\) of working volume but for good circulation the height of boiling massecuite should not exceed 1.5 m. and to achieve these twin objectives the size of the pan belt above the upper tube plate of calandria is increased in diameter. Thus the diameter of massecuite belt is made larger than that of calandria by 0.6 - 1.6 m. the two being joined to each other by a sloping cone. The advantages of low head pans are

(a) low graining or footing volume, about 25-30% the strike volume,

(b) good natural circulation of massecuite even when the strike level reaches the maximum limit, resulting in reduced time of boiling,

(c) higher H.S. to volume ratio can be maintained which adds to the speed of boiling.

5.5. Major design considerations—In pan boiling along with speed of boiling a strike, it is important that no pockets of stagnant mass remain inside the pan which will not only affect the quality of sugar but will bring about destruction of sugar also. In vacuum pan operation maximum exhaustion of mother liquor is aimed at along with proper development of crystal size and shape. The factors which come into play in achieving the desired results in respect of pan design are as under—

(a) Even distribution of steam in the steam belt and effective removal of incondensible gases are inter-linked in the sense that the steam path is so arranged as to drive the incondensible gases to the points of their removal. In pans of large capacities two steam entry points are provided in the calandria. Needless to state that the condensate extraction from the bottom of the calandria should leave no accumulation. The steam must reach all pockets of the calandria, in a uniform manner for efficient heat transmission to the massecuite in the tubes.

(b) Low graining volume or footing volume is useful when a footing is to be cut into a vacuum crystalliser or another pan and similarly it reduces the amount of footing the pan is to be filled up with. Low volume is very helpful for grain development in high grade boiling and purity control in low grade boiling.

(c) The height of the stike when full above the top tubeplate of calandria has to be low for two reasons—

(i) the high hydrostatic head raises the boiling point of mass in contact with heating surface particulary in the lower portions of the calandria,

(ii) Circulation rate is lowered at top portion as height of strike increases, which in other words means that the velocity of movement of massecuite through the tubes upwards and its return to the bottom is reduced.
(d) Introduction of feed of syrup or molasses in the system has to be such that the feed is quickly dispersed uniformly in the upward moving mass.

(e) With the recent trend of employing vapour from pre-evaporator for vapour boiling, it is essential that the pan design in respect of heating surface to strike volume ratio and distribution of vapour should be suitable for boiling pan at about 0.2 kg/cm².

(f) Entrainment separation has to be efficient as during early stages of the strike boiling, when the brix is comparatively low chances of carry over of liquid with vapour make it necessary to effect efficient separation of liquid from the rising vapour.

6. DIFFERENT DESIGNS

In view of the above requirements of the pan boilings, and for improving circulation characteristics, different designs of pans have been introduced, some of which are as follows—

(a) Floating Calandria—In a floating type calandria, in place of central down take the downward movement of the descending massecuite is provided in the annular space. The heated massecuite rises towards the top and flows radially towards shell and downwards through the annular space. In one design the calandria is conical shaped at the bottom and flat at the top, which has added to the heating surface. In the conical bottom type floating calandria designed by Hugot the steam connection is provided at the centre through pipe passing through the save all at the top. One great disadvantage with floating calandria pans is that mechanical circulator can not be installed in such pan.

Segura pan—This pan has a floating type calandria with some special features with respect to steam entry and peripheral downtake. The top tube plate is in horizontal plane but the bottom tube plate possesses the shape of inverted cone with tubes becoming shorter from centre to peripheri. In the downtake are fitted 20 inclined baffle plates to guide the massecuite. The steam entry is provided at the centre of calandria, the steam pipe entering in the steam chest, at the bottom. The steam pipe is shielded by larger pipe inside the pan and vacuum is maintained in the gap between the steam pipe and outer pipe to avoid overheating of massecuite above the upper tube plate. The pan feed of syrup or molasses is arranged through an outside pipe forming a ring from which feed enters the peripheral downtake at different points. This pan design permits fast boiling and use of low pressure vapour or steam. Moreover the footing volume is also low. In view of the good circulation characteristics the pan needs no mechanical circulation.

(b) Conical calandria—This type of calandria has a central downtake but the tube plates of the calandria are inclined towards the centre, the lower tube plate being at 25° and the upper one at 10°-25°. The idea behind the top tube plate sloping towards centre is to render washing and cleaning of top of calandria easy after the pan is dropped. The inclined conical shape provides higher heating surface, less idle space in the bottom cone and lower graining volume as compared to conventional central downtake straight type calandria.
(c) **Ring type calandria**—The Grantzdorffer design of calandria is characterised by concentric rings which are on the same level at the top but are extended downwards so as to form a conical bottom conforming to the shape of bottom cone of the pan. The massecuite circulates through the rings and the central downtake. In the improved version of this type of calandria designed by Tate & Lyle the rings are made of ribbons. The steam inlet for the rings is at the top while the condensate drains out from bottom of the elements. The annular ring design is good for efficient circulation and these are widely adopted in refineries. The refinery strikes can be concentrated to 95° Bx due to ease of discharge and very high yields of sugar are obtained.

(d) **Horizontal design**—In a recent design of horizontal pan of Fives Lille-Cail the heating surface is provided by hollow plate type elements vertically placed. The shape of the pan permits of low footing volume (upto 26%). The heights of elements increase towards the centre from the periphery. The massecuite is dropped through three openings at the bottom. The ratio of heating surface to strike volume can be varied from 6 to 7.5 m²/m³.

(e) **Rotary horizontal pan of Lafeuille design** has the merit of low hydrostatic head and rapid boiling on account of low resistance to circulation and good heat transmission. Nests of tubes constitute the heating surface and the space between these nests provides passage for massecuite circulation. Fixed connections for steam, vacuum, incondensible gases are attached to the plain ends of the rotary cylinder. The discharge of strike is effected through 2-3 openings. One such pan was installed at Ravalgaon for producing extra white sugar of large size from melt. This pan can boil strikes to a very high brix. However this rotary type construction of pans has not found much favour with manufacturers of sugar machinery or technologists.

(f) **Other designs**—In one pan designed in India the steam feed is provided at the centre as in Segura design, the steam pipe being extended to the bottom of calandria and the pipe inside the calandria has openings for radial distribution of steam. The pan has peripheral downtake for circulation of massecuite. The saucer bottom pan developed in Hawaii has a shallow bottom shaped to assist circulation of massecuite. The calandria is of conventional central downtake type but because of the special shape of the bottom the footing volume is low and the discharge valve is on one side at the lowest level. In the Fletcher design the downtake of calandria is almost half in diameter of the calandria and the syrup and molasses feed is arranged in the central portion of the downtake so as to get mixed with the descending massecuite before it starts rising in the tubes of calandria.

A pan designed by Cail has the unique feature of special arrangement of the calandria with lateral downtake. This downtake is either biconvex type or crescent type, with cross section of 20% and 22% cross section of the pan interior respectively. Thus the descending massecuite flows along the exterior of the wall which is comparatively cooler and efficient natural circulation is achieved.

(g) **Pan with internal condenser**—In the conventional system the pan is connected through
a large vapour pipe to the condenser and to reduce the space required and save on vapour piping in South Africa, a new design of pan known as Darnell pan was introduced wherein the condenser is located in the head box of the pan. The condenser is a barometric rain type made of stainless steel. In the Queensland design of pan with internal condenser the condenser of conventional rain type is located centrally in the head box and the condenser leg passes straight through the centre of the bottom. If mechanical circulator is to be installed the torricellian leg will be from the side of the massecuite belt.

To protect it from corrosive action of vapours, the condenser should be made of stainless steel plates.

7. CIRCULATION AND EVAPORATION

7.1. Efficient natural circulation of the massecuite is essential for proper crystal growth and achieving good boiling of the strike at reasonable rate. The circulation in a pan results from the heating of massecuite by the heating surface of the tubes, and the vapours together with the heated mass rise upwards while the comparatively cooler massecuite descends through the central or annular open space of the calandria. Out of these two factors viz., rising bubbles due to application of heat and the difference in the densities of upward moving massecuite and the descending column of massecuite, the main motive force which promotes circulation is the upward rise of vapour bubbles from the massecuite heated in the tubes. Thus in a well designed pan heat transmission from heating vapour will decide the circulation rate.

7.2. The resistance to circulation is caused by—

(a) upward passage through the tubes and
(b) downward movement of massecuite through the centre well or annular space.

Thus the total resistance to circulation will be governed by—

(i) tube diameter,
(ii) tube length
(iii) number of tubes and
(iv) the free passage for the descending mass i.e. the diameter of centre well in the case of calandrias with central downtake and annular free space of the floating calandria.

As regards internal diameter of the tube, it can very from 76.3 mm. (3") to 127 mm. (5"). The larger diameter on account of less friction obviously offers less resistance to passage of massecuite but has the disadvantage or giving much lower heating surface whereas the small diameter tubes will give much higher heating surface for equivalent volume but it is not conducive to circulation of high brix massecuites. In India the standard practice adopted of use of 96 or 98 mm. internal diameter tubes for pans is thus a compromise between the above two extremes. Variations in tube diameter for different capacities or grades of strikes is also not favoured on account of increased inventory of stores.
length of tubes they may vary from 850 mm. to 1.75 m. in length. However according to Webre and others, greater heat transfer is obtained with shorter tubes. As the massecuite rises in the tube, the heat transmission progressively diminishes and the upper portions of the heating surface play less significant role and for this reason some investigators prefer to restrict the tube length to 900 mm. as increasing tube lengths beyond this according to them amounts to a waste of material. In the calandrias with central downtake the optimum ratio of diameters of centre well to that of the calandria diameter is 0.4 i.e. 40% and thus the calandria diameter is 2.5 times the size of the free passage of the descending column of the massecuite. In respect of floating calandria pans according to Hugot the optimum ratio of diameter of calandria to that of the pan is 0.82 - 0.84.

7.3. **Effect of B.P.E. and Hydrostatic Head**—Boiling point elevation B.P.E. is related to the rise in boiling point of solution containing solute over that of pure solvent at the same pressure. B.P.E. is higher, higher the brix of massecuite and higher the nonsugar content of solution. In the case of massecuites this rise in boiling point will be around 8° - 12°C over that of water, at the surface of the boiling mass. At 635 mm. vacuum the boiling point of water is 56.2°C whereas a 90-92° Bx massecuite will boil at temperature of 65° - 66°C depending on the purity. Below the surface at the depth 30 cm. the pressure in the massecuite will be higher due to the weight of massecuite columns which has a density of 1.4-1.5 and because of this pressure the boiling point of the material at that depth will correspond to the boiling point of water plus the boiling point elevation at that pressure. Thus in the absence of fast circulation the temperatures of massecuite will go on increasing with depth. The rise in temperature is however closely associated with drop in supersaturarion and even if the surface layer of massecuite is supersaturated, with gradual decrease in supersaturarion as we pass to lower depths a stage is reached when some layer of massecuite at a certain depth will be at saturation temperature and below this level the massecuite will be in unsaturated state with the result that crystal dissolution will start.

This however does not represent the true picture of the massecuite boiling in practice since the massecuite is circulating in the pan and layers of boiling mass are replaced constantly. Under ideal conditions of circulation uniform temperature of boiling obtains throughout the boiling massecuite irrespective of the hydrostatic head or the height of the strike in the pan. In practice conditions in pan in respect of circulation are far from ideal particularly as the pan gets filled and massecuite level rises. Initially when the footing is drawn in and boiling started the rate of circulation is pretty high but as the strike level rises the circulation slows down. This fall in circulation rate is commonly noticed in final massecuite boiling in pans without mechanical circulation. Studies conducted with a well designed pan with natural circulation, showed the following circulation velocity at various levels of the strike.  

<table>
<thead>
<tr>
<th>Table showing Speed of Circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st hour</td>
</tr>
<tr>
<td>2nd hour</td>
</tr>
</tbody>
</table>
3rd hour 4.6 cm/Sec.
4th hour 0.9 cm/Sec.
5th hour 0.6 cm/Sec.
6th hour 0.3 cm/Sec.

It is the common experience that boiling rate of a final massecuite strike slows down considerably after reaching level of 1.0 m. above the tube plate, even when the pan is properly designed with regard to downtake, bottom cone and heating surface to volume ratio.

As stated earlier, the circulation of massecuite is the result of displacement of every layer of the material, by another fresh mass and when this rate decreases local overheating of massecuite at different depths is obtained. Local high temperature attained by massecuite will have two consequences

(i) wherever temperatures rise high enough to cause unsaturation, crystals dissolve

(ii) contact with heat leads to undesirable colour formation.

In view of the above limitations and shortcomings of natural circulation, mechanical stirring of boiling massecuite was conceived long back and abandoned on account of faulty design. This concept was revived by Webre who introduced new mechanical circulator design after conducting studies on the circulation characteristics of pans with natural circulation.\textsuperscript{23}

8. MECHANICAL CIRCULATION

8.1. To a shaft inserted in the pan from the top is attached a screw pump impeller which has the same diameter as the calandria downtake. Six vanes are attached to the propeller drum to guide the descending column of massecuite towards the tubes of the calandria. The shaft is supported in the centre of downtake by bearings and is coupled to an electric motor through a reduction gear located on top of the pan dome. An indicating ammeter provided for the motor serves to indicate the current and load variations during boiling, which assists in regulating feed to the pan. A funnel shaped deflector mounted at the edge of the centre well prevents shortcircuiting of massecuite at the top of the tube plate, by guiding the rising hot massecuite towards pan wall and avoiding the mixing of part of rising hot massecuite with downward current of cooler mass. For 72.0 purity Webre has observed following evaporation coefficients for both natural circulation and mechanical circulation.\textsuperscript{24} (in Kg/m\textsuperscript{2}/hr.)

<table>
<thead>
<tr>
<th>Pan with Natural Circulation</th>
<th>Start</th>
<th>Finish</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28.74</td>
<td>1.03</td>
<td>9.27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pan with Mechanical—or—do—</th>
<th>Start</th>
<th>Finish</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>29.65</td>
<td>10.30</td>
<td>17.25</td>
</tr>
</tbody>
</table>
The Webre circulator was designed for a circulation velocity of 45 cm/sec. with 3 seconds’ contact of massecuite with heating surface but later tests in Australia gave velocity of 20 cms./Sec. in the beginning dropping down to 5-10 cms./Sec. at the end of ‘C strike. Nevertheless this marks considerable improvement over pan with natural circulation.

The load on motor goes on increasing as the massecuite level rises in the pan, reaching maximum during the final phase of tightening the strike and the ratio of minimum to maximum power requirement is around 0.4. Average power consumption is about 1.05 Kw/M$^3$ of capacity of the pan while the maximum would be higher by 75% and thus the nominal installed power will have to be 25% above the maximum. Speed of circulator for high grade massecuite is 80 RPM but for final massecuite it is maintained at 60 or 50 rpm. Webre maintains constant speeds but D.D.S. favours adoption of two speeds normal upto filling stage, and during heavying up it is halved. This necessitates installation of two speed motors or hydraulic drive.

8.2. Advantages—There can be no doubt about the desirability of installing stirrer in a pan for final or ‘C massecuite boiling pans in view of the benefits accruing from improved rate of circulation. The improvements in the massecuite boiling on account of mechanical circulator can be stated in brief as under—

(a) The massecuite boiling time for final massecuites is reduced by 30-40%.

(b) Strike level in pan can be raised by 30-40 cms. with introduction of stirrer.

(c) Even and uniform grain size can be maintained throughout boiling.

(d) For high grade pans conglomerate formation is prevented.

(e) Colour development due to local overheating is considerably reduced.

(f) Saving in steam consumption results from reduction of boiling time.

(g) Low pressure vapour can be used for boiling.

In Indian Industry, according to author's experience mechanical circulator for ‘C or final massecuite boiling certainly yields very good results in improving the performance of pan, reducing boiling time and assisting proper exhaustion of molasses.

Disadvantages—

(a) higher power consumption

(b) extra investment required,

(c) higher maintenance costs.

Slimming up it can be stated that for high grade pans unless due to faulty design the circulation and boiling rate are poor the mechanical circulator may not be essential but for final massecuite boiling pans it is certainly advantageous to instal mechanical circulator.
9. INSTRUMENTS

9.1. Pan boiling involves evaporation and crystallisation which in effect means, concentration of material of different purities and growth of sugar crystals to the desired size. A pan boiler has to control the steam to calandria and pan feed to suit the rate of evaporation and development of crystals. A pan must be fitted with

(i) vacuum gauge in the shell,

(ii) temperature gauge for pan belt

(iii) pressure gauge for vapour or steam chest of calandria, for the panboiler to know the conditions inside the pan with respect to pressure and temperature. In addition to these simple gauges and meters, in modern pans special instruments are fitted, which serve as aids to control of pan boiling operation. Control of panboiling is essentially related to supersaturation and crystal growth which in turn are dependent on concentration of the massecuite.

9.2. Conductivity instruments—These instruments are based on the principle that conductivity of sugar solutions is directly related to water-content of sugar solution which determines the concentration and supersaturation. Application of principle of electrical conductivity to controlling the process of crystallisation in pan boiling was originally conceived and developed by P. Honig.\textsuperscript{27} His work was based on Walden's findings that in solutions of same electrolyte content the conductivity multiplied by viscosity is a constant. A conductivity control instrument was developed by Java Experiment Station which was named by the British manufacturers as 'Cuitometer' which became popular in different sugar producing regions including India. Two copper electrodes are inserted inside the pan in the zone of normal circulation in such a way that the axis of electrode is perpendicular to the flow of massecuite. The diameter of electrodes and the distance between these, as also the length of electrode have definite ratios. The electrodes are encased in insulating material like plastic which has extremely low electrical conductance, sufficient mechanical strength and ability to withstand heat during pan steaming. The system of separately mounting two electrodes has now been replaced by inserting one holder in which are fixed the two electrodes. The set of electrodes is so mounted that it can be removed during periodical shut down for descaling. As stated earlier the electrodes are fitted in the centre well or below the calandria in the normal passage of circulating massecuite, and to avoid any disturbance in the conductivity readings they must be placed at sufficient distance from the wall of the pan or calandria plate.

To overcome the disturbances in conductivity readings on account of scale deposition on electrodes, contactless electrodes have been developed in Australia,\textsuperscript{28} based on the principle of using radio frequency currents for measuring conductivity of liquid without the electrodes being in contact with liquor. A.C. supply is connected to electrodes, with adjustable voltage. The conductivity is measured by millimeter, in milliamperes even at normal frequency i.e. 50 cycles but higher frequency current gives greater accuracy.

In this system the electrode is enclosed in an insulator and flow of electrical energy from
this conductor to another is by capacitive coupling. With high frequency, it is possible to get measurements of current passing through the massecuite. Yet another deviation from the original system is the use of two electrodes of dissimilar metals introduced, by Ducasse in South Africa. By applying small potential difference between two metal, small direct current is produced in the circuit and indicated on instrument. Following this principle it is possible to use one zinc electrode, while mild steel pan wall can form another electrode. The current has to be measured by microammeter as direct current. The current is read from the meter and also recorded on recorder.

10. Recent investigations at the Central Electronics Engineering Research Institute, Pilani, India, have led to modifications in the system of crystallisation control on the basis of conductance through massecuite, on applying A.C. at low voltage. Studies by C E E R I showed the limitations of the conventional method of conductance measurement utilising ohmmeters type circuits; which suffers from poor sensitivity on account of line voltage fluctuations and continuous change in the capacitance of the massecuite between the electrodes resulting from change in the dielectric constant. This led to the development of A.C. resistivity based instrument known as 'panometer' which has a circuit configuration, that indicates A.C. resistivity while at the same time eliminates dielectric effects and capacitive coupling effect. Essential components of the panometer circuit are—

(i) amplitude stabilised oscillator
(ii) active low pass filter and amplifier.

Measurements are made at high frequency of 10 KHz.

Two electrodes mounted in a holder are of stainless steel square bar type while the resistivity readings are displayed on analogue meter. These instruments designed on the basis of latest I.C. technology have been performing well in many sugar mills and it is possible to control feed to the pan and steam to calandria automatically employing panometer instrument, which enables the steady maintenance of the desired supersaturation.

While using the conductivity meter for pan boiling control it has to be borne in mind that the readings obtained indicate the degree of supersaturation. For any factory in conducting the final or 'C massecuite boiling it is possible to determine the range of readings for different stages of boiling like, development of footing, boiling at medium brix, heavying up and movement water application. In combination with mechanical circulator load readings the conductivity or resistivity indications can be successfully used for final massecuite boiling as per author's experience in Deccan.

11. SUPERSATURATION

11.1. The B.P.E. or boiling point elevation, which is the rise in boiling point of solution due to presence of solute is closely related to supersaturation in that at a particular purity and
temperature the supersaturation can be determined by dividing B.P.E. of a given solution by the B.P.E. of the same solution at saturation. It is thus possible to control pan boiling operation by observing the supersaturation and this system has been in vogue in the sugar industry in the past seven decades or so though of late greater precision has been achieved by more complex methods to suit automatic control of pan boiling. The B.P.R. values of saturated sugar solutions of different purities have been worked out on the basis of work of Holven and Gillett. Use of this method requires determination of two temperatures one the temperature of massecuite and another boiling point of water at the same absolute pressure as obtained in the pan. The difference between these two temperatures is the B.P.E. or B.P.R. For determining the massecuite temperature it is essential to insert the sensitive element of the thermocouple or thermometer in the centre of downtake i.e. in the descending passage of circulating massecuite. For the other temperature of boiling water one way is to insert thermometer in a small vessel connected to vapour space of the pan, which contains boiling water. Yet another method is to install an absolute pressure gauge and to read from the chart attached to the thermometer, temperature of vapour at the prevailing absolute pressure and consequently the B.P.R. can be found out.

11.2. Holven's method of direct measurement of SC—Studies by Holven led to the development of automatic supersaturation measurement with the help of an electric circuit containing wheatstone bridge. The currents from the resistance thermometers are converted into supersaturation values with necessary adjustments and correction for the difference in true and apparent purities. The theoretical background of this method can be explained in brief as under—

(i) When on a graph of boiling temperatures of supersaturated sugar solutions v/s boiling points of water is drawn, the lines converge to one point,

(ii) These lines are straight within the range of absolute pressure met with in pan boiling,

(iii) The tan $\theta$ of the angle formed by any line with horizontal is an index of supersaturation,

(iv) The ratio of temperature difference between the boiling point of water and reference temperature as also that between the boiling temperature of massecuite and reference temperature under identical conditions of absolute pressure gives supersaturation of the massecuite.

\[
\tan \theta = \frac{TW - K}{Ts - K}
\]

Where Tw and Ts are temperatures of boiling water and the sugar solution and K is the reference temperature.

The electrical circuit consists of one wheatstone bridge circuit connected to a resistance thermometer in a pilot pan and another connected to resistance thermometer of the pan. The ratio of the potential differences of these wheatstone bridges indicates the supersaturation which can be measured on slidewire.
12. MOBILITY OR CONSISTENCY

In boiling a strike, charge of syrup or molasses is given when the massecuite becomes thick and thus viscosity or consistency of massecuite can give good indications regarding the requirement of feed to the pan. An instrument developed for indication of consistency and record it, known as Tor con consists of a rotating paddle driven by a fractional hp motor, running, at constant speed. The torque variations in rotating the paddle at constant speed are converted into proportional electric output signals which are indicated, recorded and can also be utilised for regulating pan feed valve.

13. CRYSTALSCOPE

This instrument is mounted on the pan for observing crystals on the screen, throughout the process of boiling. The crystals projected on screen give an idea of the uniformity and shape of sugar crystals in the pan. This instrument is useful for first massecuite from which white sugar is produced and also for final massecuite pan. However it is not connected with automatic control of operation.

14. MASSECUITE LEVEL

Massecuite level measurement is necessary for automatic control of panboiling and also for understanding the level of strike in a pan above the front sight glasses. The level transmitter instrument consists of a diaphragm inserted in the bottom space of the pan, which is balanced by air pressure on the other side which checks movements of diaphragm. A differential pressure between the balancing pressure and pressure inside the pan is recorded which indicates the level of massecuite when the massecuite brix is the same.

15. AUTOMATIC CONTROLS

15.1. Automatic control instrumentation is essentially based on any one of the above principles whereby the desired degree of supersaturation is maintained by controlling the feed to the pans as also other parameters like level of strike, vacuum, steam supply etc. Some of these systems adopted in sugar industry are described below—

15.2. Feed Control—Out of the different parameters to be controlled in the panboiling simplest would be the feed control system either based on conductivity or consistency or even supersaturation. A pneumatic valve for feeding syrup or molasses to pan is connected through an electronic circuit to the conductivity instrument. The upper and lower limits of conductivity are set for each phase of pan operation and the valve opens or closes automatically once those limits are reached, as for instance when the supersaturation reaches high limits as indicated by conductivity meter, the autovalve opens and closes after the lower set limit of supersaturation is attained. Similarly by employing electronic circuit and controller for regulating the charging valve it is possible to control feed by supersaturation instrument and also consistency instrument. Such feed control systems
can be developed without much complications but other conditions of pan like vacuum, steam supply, strike levels have to be manually controlled by the panboiler.

15.3. Full automatic control—In the D.D.S. System\textsuperscript{34} in addition to two bottom electrodes there are seven level electrodes located one above the other which control the charging in different stages of boiling according to the programme. The control system consists of pneumatic valves for syrup and molasses charging, water and seed inlet. Besides these a pneumatic control valve is installed in the injection water inlet to condenser for regulating vacuum. Absolute pressure transmitter is mounted in the top of the pan and is connected to controller regulating the vacuum. The entire control system comprises different modules relating to timers, conductivity controller, vacuum controller, programming unit and other functions. The boiling is conducted as per the programmed conductivity controller. In recent years the electropneumatic system has been replaced by complete electronic system which lends itself suitable for communication with computer and a programme is developed to carry out all operations from start up to discharge of the pan into crystalliser.

15.4. The system of automatic pan boiling operating at Pravara S.S.K. in Deccan, designed by Mera—PNEFAL of Poland\textsuperscript{35} is based on control of variables on the basis of measurement of fluidity or viscosity for high grade boiling and conductivity for low grade massecuites, together with the level measurement. A motor driven rotor turning in the boiling massecuite detects consistency and the output signal is proportional to the torque. The massecuite level is determined from the hydrostatic pressure of massecuite. The low grade boilings are conducted by using conductivity probe and conductivity transmitter which regulates the drinks of molasses and water. The conductivity probe is mounted at the bottom of pan below the calandria in the region of circulation of the massecuite. The controllers are programmed to take care of

(i) taking the footing,

(ii) boiling,

(iii) cutting the pan

(iv) second boiling and tightening in the case of high grade pan.

In the case of low grade boilings one more function is added to the programme viz. graining by slurry method. The manual operations include control of steam or vapour, starting the pan, discharge of strike and washing the pan.

15.5. In yet another system established in a few factories like Panchaganga S.S.K. Ltd.\textsuperscript{36} in Deccan, the control is based on supersaturation which is arrived at by measurement of temperatures of the vapours leaving the boiling mass and water boiling at the same absolute pressure whereby Boiling point elevation is known. The B.P.E. is converted to supersaturation by electronic circuitry and displayed. Consistency probe in mounted in the pan and the setting of lower and upper limits on scale, regulate the feed to the pan. The absolute pressure transmitter is provided for regulating flow of water to condenser and thereby the pan vacuum. Strike level control is a diaphragm type differential pressure transmitter located at the bottom of pan. In short the control system monitors
and controls, consistency, strike level, absolute pressure and over saturation and thereby steam, charging to pan and water are automatically controlled as per the programme worked out for each type of boiling.

15.6. It is possible to control the entire pan boiling right from starting the pan upto steam washing at the end of the dropping of strike, making use of microprocessor based circuits, controlling the various parameters involved in boiling and following the elaborate sequence of operation. It is desirable to check the programme of control so that it conforms to proper cycle of operation for getting good results. Automation of panboiling undoubtedly gives improved performance provided the control system is programmed to suit the needs of good massecuite boiling. The advantages are—

(a) reduction in time of boiling,
(b) reduction in steam requirement,
(c) uniform and even sized crystals,
(d) higher recovery of sugar by better exhaustion.

16.

16.1. For conducting pan boiling operation, besides the vacuum pans, some more units are necessarily installed on the panfloor for

(a) storage of syrup and molasses,
(b) seed and footing
(c) conditioning of molasses feed to pans.

Their capacities are related to the capacities of pans and the amount of massecuite of each type being produced. The details of these ancillary units as installed in modern white sugar producing plants are given below—

16.2. Pan supply tanks—There are 12-15 storage tanks for syrup, melt and molasses from different massecuites. The tanks are rectangular in shape and of M.S. construction, the total holding capacity being about 0.75 to 1 h.l. per t. cane crushed per day. Depending on the type of material i.e. A heavy, B heavy, C light or syrup, melt, two to four tanks are arranged in a nest or group and tanks for similar material are interconnected. This way all syrup tanks will be interconnected and so will be arrangement for each type of molasses like A heavy, B heavy etc. Feed to the tank is from overhead pipes with suitable valves while the outlets of tanks from bottom are joined to three different pipes, viz. one for melt, A light and syrup, one for A heavy and one for the last one or two stages of boiling. Pan supply tanks are connected to the respective pipes through valves to corresponding pans. The molasses tanks are provided with steam coils at the bottom and are thoroughly lagged. A common washout pipe is laid below the pans for cleaning the tanks, the washings being led to raw-juice receiving tank.

16.3. Molasses conditioners—The molasses or mother liquor from different massecuites, received
from centrifugal station invariably contain fine grains of sugar which must be dissolved by heating and dilution for which special conditioning equipment is installed. The conditioning tank has steam and water connections. Molasses from the pan supply tanks is received in these tanks and only conditioned molasses is fed to pans. A simple arrangement for molasses conditioning was developed at Phaltan Sugar Works consisting of a closed gutter with a number of baffles and provided with steam and hot-water connections. This apparatus was installed above the molasses tanks so as to treat the molasses before entry into supply tanks.\textsuperscript{37}

16.4. Seed crystallisers and vacuum crystallisers—

For high grade boiling seed footing consists of magma of white sugar or washed sugar from 'B' massecuite and this seed magma is stored in a crystalliser fitted with a motor driven stirrer revolving at 60 r.p.m. In some factories two crystallisers are installed for separate storage of white sugar seed and magma from 'B' massecuite curing. Vacuum crystallisers are used for storage of footing for low grade massecuites and are fitted with suitable connections for vacuum, and interconnecting pipings of pans. The sight glasses fitted to the vacuum crystallisers enable observing levels inside the crystallisers. The capacity of the seed crystallisers is approximately equivalent to half the capacity of one high grade or 'A' pan while the volume of the vacuum crystalliser is usually three-fourth the capacity of one low grade pan.

16.5. Centrifuging 'B' heavy molasses—Since the sugar from 'B' massecuite curing is either used as seed for 'A' boling or melted, and the melt is used in 'A' boiling, the suspended impurities in 'A' Heavy which to some extent get embedded into crystals formed in 'B' boiling will find their way into white sugar. Similarly the melt from 'C' sugar which is used entirely in 'A' boiling contains the suspended impurities of the mother liquor from which the crystals are developed. Honig had proposed way back in twenties the centrifuging of 'A' heavy and 'B' heavy molasses in Java to eliminate the suspended nonsugars.\textsuperscript{38} Studies by D.P. Kulkarni have shown sudden increase in suspended impurities from syrup to A heavy in white sugar process, these molasses containing from 1.7 to 3.3% suspended matter on 100 brix of original liquor.\textsuperscript{39} James C.P. Chen and Felix Proskowetz have reported purity rise of 3.4 units by centrifugation of 'B' heavy molasses, the separated sludge containing 35 to 50% ash.\textsuperscript{40} Similar experience in Australia has been reported with regard to elimination of nonsugars in 'B' heavy, and improvement in the performance of 'C' boiling.\textsuperscript{41} The advantages from this treatment would be

(i) lowering of final molasses loss due to increase in R.S./ash ratio and lowering of viscosity,

(ii) improvement in 'C' sugar quality with reduction in ash in final sugar.

Nevertheless the centrifuging of 'A' heavy of 'B' heavy has not found universal adoption in white sugar manufacture as yet.
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PART-II

CRISTALLISATION

1. PROCESS OF PAN BOILING

1.1. The process of pan boiling for plantation white sugar manufacture differs considerably from that followed in raw sugar plants and also sugar refineries, in as much as the objectives in this case are to produce white crystalline sugar from syrups of purities varying from 77 to 86 and at the same time to ensure minimum loss of sugar in final molasses. In some parts of India market requires big grain sugar of 1.5 to 2 mm. size and since the big grain sugar of good whiteness fetches premium, the factories have to adopt methods suited to produce as much big grain sugar as possible by boiling 'A' massecuites from which white sugar is marketed, in high purity medium. However to bring down the final molasses purity, the final massecuite purity has to be as low as practicable, which many times calls for practising four stage boiling in place of the conventional three massecuite system. The design of pan station has thus to take into account these two factors in respect of capacities provided for pans, pan supply tanks, seed crystallisers and other accessories.

1.2. Terms used—The sugar crystals first appear in pans in the entire process of sugar manufacture and the mass of sugar crystals together with the liquor surrounding the crystals is termed as 'Massecuite' derived from French 'Masse cuite'. In literature one frequently comes across word 'Fillmass' which is synonimous with massecuite. The word 'Strike' is also commonly used in factories in place of massecuite. These massecuites are designated by letters as A, B, C depending on first, second or third stage of boiling respectively.

Preparing footing is development of grain or seed to sufficient size for further massecuite boiling. The massecuite boiling usually is completed in three stages

(a) grain development or seed development,
(b) transferring or cutting footing into vacuum crystalliser or another pan,
(c) boiling massecuite on the footing.

The 'Molasses' is the mother liquor separated from sugar crystals during centrifuging of massecuite. When the molasses is separated with minimum washing in centrifugals or without any application of water it is comparatively of high brix and low purity and is denoted as heavy molasses like A Heavy from A massecuite B heavy from B massecuite. Separation of heavy molasses is followed by liberal wash or resorting to second time curing in centrifugal. The liquor thus obtained is of higher purity than the heavy molasses and is named as light molasses and from A massecuite A light is obtained after A heavy is separated and similarly for 'B' and 'C'.

Final molasses is that mother liquor obtained from final massecuite from which sugar can no longer be crystallised out economically with the present technological practices.

In a similar fashion the sugars from different massecuites are known as A Sugar, B Sugar etc., The sugar from first curing in case the massecuite is double cured is known as forecured sugar of that massecuite and from second curing as afterworker sugar.
2.

2.1. Certain basic principles underlying the practice of pan boiling are to be scrupulously followed for obtaining good results at the crystallisation stage in view of the fact that the inadequacies or errors in the boiling of massecuites in pans cannot be rectified in later stages of the process. These are briefly dealt with below—

2.2. Recirculation of sugars and nonsugars—The sugar bearing liquids being sensitive to heat it is natural to expect that the more we boil the syrups and molasses the more losses of sugar are obtained. The sucrose and reducing sugars undergo transformation due to prolonged heating the extent of decomposition depending on the time and temperature. This is in accord with the experience that massecuites boiled at lower vacuum or high temperature contain more colour, and also if the final massecuite curing is poor resulting in more recirculation of nonsugars the massecuites boiled subsequently are highly coloured and viscous. The nonsugar recirculation is invariably accompanied by recirculation of sugar in the process of boiling and organic nonsugars also undergo undesirable transformation as a result of prolonged heating. Thus irrespective of the process of boiling adopted, recirculation of sugar and nonsugars is to be minimum for which in the practice of boiling and subsequent operations—

(a) The massecuites must be concentrated to a high degree to achieve good desugarisation of mother liquor and

(b) the separation of molasses from sugar crystals has to be efficient.

Thus no reboiling of mother liquor from any massecuite in the similar category of massecuite is practised, for example the 'B' heavy should not be boiled in 'B' boiling again.

In short the aim in the entire process of boiling is to arrange shortest path for both sugar and nonsugars to sugar bags and molasses respectively.

2.3. The brixes of massecuites at the time of dropping have to be as high as the equipment permits. At the beginning of strike when the strike level is low the brix is not high but as the grain size increases and the strikes builds up the brix during boiling is gradually raised, reaching maximum limit prior to discharging the strike. Heavy boiling of strikes in refineries has been found to give higher recovery of sugar per unit volume of strike and at Tale & Lye refinery the pan and crystalliser designs have been specially made to suit handling of very high brix massecuites.1 The control of brix of massecuite during boiling should be however carefully planned and executed so that no conglomerate grains are formed nor is secondary or false grain produced at any stage in the boiling in view of their deleterious effect on centrifuging and crystal uniformity. Similarly the heavying up at the end of the strike should be such that the maximum brix is obtained after dropping the strike but at the same time sufficient fluidity is maintained for discharge of strike and the crystalliser elements to stir the same.

2.4. Purity Control—In white sugar manufacture as the syrup purities vary from 77 to 85-86 during different periods of crushing campaign the first boiling or A boiling purities will also undergo variations from 85-90 despite the amount of low-grade sugar melt being
used and rigid control over the purities of molasses from different massecuites like B and later stages of boilings is absolutely necessary to bring down the loss of sugar in final molasses. This in turn calls for variation in the number of strikes i.e. adoption of the three or three & half or four massecuite system to maintain the desired low purity of final massecuite.

The purity control of massecuite depends more or less entirely on the purity of feed liquor and thus while boiling the low purity massecuites wherein more than one type of feed molasses is to be used the proportions are to be determined judiciously. The purity of mother liquor from any massecuite depends on

(i) brix of massecuite

(ii) purity of massecuite,

(iii) extent of washing at centrifugals under normal conditions of juice composition besides the extent of cooling in crystallisers.

2.5. Feed—The molasses fed to the 'B' and other low grade boilings, must be diluted to around 70° Bx and heated to about 70°C i.e. slightly above that prevailing in the pan. This has two-fold effect—

(i) the fine sugar grains in molasses as received from centrifugals are dissolved and

(ii) feed is rapidly mixed with the massecuite in pan.

This conditioning of molasses is accomplished in special apparatus provided with steam and water connections. The molasses must be free from fine grain since it is undesirable to have mixed sized grains in boiling a strike on seed footing which has a definite size of grain.

2.6. Seed for 'A' Pan—In white sugar producing plant seed for 'A' pan must be as white as possible. The usual practice is to use fine white sugar magma from sugar-house and supplement it with well washed sugar from 'B' massecuites. Many times a factory has to use large quantities of 'B' sugar seed and it is advisable to double purge such 'B' massecuites to ensure supply of good quality seed for 'A' boiling and also to keep purity of 'B' heavy molasses under control.

2.7. Operating conditions—Operating conditions of pan boiling are dictated by steam supply, optimum vacuum as also supply of feed and for good pan boiling operation with respect to process control these conditions have to be steady without any fluctuations. In a smooth running plant working to full capacity and practising vapour bleeding from evaporator to pans sometimes the vapour supply can be fluctuating unless the evaporator is equipped with automatic controls but steam bleeding into vapour line can rectify this by maintaining constant vapour pressure. As regards the vacuum it is maintained at 635-665 mm. depending upon the absolute atmospheric pressure of the place. However for maintaining constant supply of feed the centrifugal operation needs to be smooth to meet the requirements of pans.

2.8. Controls—The pans must be equipped with instruments and gauges which indicate the supersaturation condition, temperature of massecuite and pressure of steam or vapour,
which are very helpful in control of pan boiling. Automatic control of various parameters of pan operation is undoubtedly extremely useful and highly desirable but in the absence of the control system at least conductivity or supersaturation indicators along with vacuum, pressure and temperature gauges must be installed and made use of properly.

3. SYSTEM OF BOILING

The scheme of boiling followed can be divided into two main categories in white sugar manufacturing viz. three or four massecuite system, the first massecuite termed as 'A' massecuite being purged for white sugar production. 'A' massecuites are boiled on seed from white sugar magma or magma made out of well washed sugar of 'B' massecuite, i.e. the second massecuite. The syrup, melt and A light from centrifugals constitute the feed for 'A' boiling, out of which syrup forms the major portion. Syrup is taken in a pan under vacuum and concentrated to around 70°Bx, followed by seed intake from the seed crystalliser. The strike is built-up with syrup, melt and A light and usually cut into another pan or vacuum crystalliser if provision is made for the same. The footing is again developed to attain the desired grain size and concentrated at the end to 93°-95° Bx before dropping. Final charges of good quality melt have been found to improve sugar colour as per the experience of technologists. The final purity of 'A' massecuite is higher than that of syrup by 3-5 units, the difference being higher when the syrup or juice purities are low since more melt from low grade strikes is fed to the 'A' pan, due to higher production of low grade massecuites. When purity of syrup is 83-84 the 'A' massecuite purity will be around 86-88. Special attention has to be paid to following factors for maintaining good standard of white sugar.

(a) seed must be white and contain uniform size grains.
(b) syrup must be bleached properly.
(c) A light molasses should be light coloured and of high purity i.e. 88-90, which is effect means that it has to be properly separated from 'A' heavy molasses.
(d) Melt must be free from molasses of the respective massecuite, the sugar from which is melted. Similarly it has to be free from sugar grains.

The 'A' strike after short cooling in the air-cooled crystallisers is cured in batch centrifugals. The heavy molasses i.e 'A' heavy has the purity of 13-17 units lower man that of the massecuite from which it is obtained. Thus the A heavy molasses of about 70-74 purity is the feed for B- massecuite boiling built on footing prepared by graining in 'A' heavy sometimes mixed with 'B' light molasses, i.e. washings of sugar from B strikes after separation of B heavy molasses, at the time of purging B massecuites. The light molasses from B curing is of somewhat higher purity than B massecuite. The B massecuite grain size is smaller than that of A massecuite and it can be tightened at the end to 95°-96° Bx before it is discharged into crystallisers.

The 'B' massecuite after being cooled to about 50°-55°C is purged in centrifugals, the heavy molasses i.e. 'B' heavy being used as feed for 'C' boiling. The purities of 'B' massecuites are usually between 72 to 78 depending on the A massecuite purities while
the B heavy molasses purities are around 50-55, as the drop in purity under good controlled conditions is 22-23 units. The C massecuite grain is made on B heavy alone or B heavy mixed with A heavy and footing built up with B heavy and C light. The pan is cut into vacuum crystalliser as the grain is usually sufficient for two or three pans and purity control of C massecuite is better when grain footing is developed for 2-3 strikes. The purities of B heavy are about 50 while the C light i.e. light molasses from second purging of C massecuite is of 54-60 purity. Footing for single strike is built up with C light and B heavy at high degree of supersaturation. The strike brix is gradually raised as the strike level increases and when the pan is filled to the top level and the desired purity of strike attained, final tightening phase starts when small drinks of water known as movement water are given to improve exhaustion as also circulation of massecuite in the pan. Attempt should be made to drop C massecuites of 100°-102° Bx. As regards the final purity of C massecuite, the former practice of discharging C massecuites of 59-61 purity has now been abandoned in favour of lower C massecuite purities of 52-55 in Deccan and 45-50 in Tamilnadu following the findings of Technologists particularly from Tamilnadu that it is possible to bring down final molasses purities by purging low purity C massecuites (45-50) in continuous centrifugals. With 48-52 purity of B heavy it may be possible to achieve 52-55 purity C massecuite but in case due to

(a) higher juice purity,

(b) lower purity drop in A boiling and curing the desired low level of C strike purity cannot be achieved it is advisable to boil an intermediate massecuite once or twice in a day with about 60 purity to be purged hot the molasses therefrom of around 38-40 purity being used for 'topping' the final C massecuite.

In case it is necessary to boil four massecuites for achieving the specified low purity of final massecuite the sugar from 3rd or last but one massecuite has to be well washed in centrifugals and melted while the heavy and light molasses are sent to pan floor to be boiled in the final massecuite. However, normally only one or two such intermediate massecuites are required to be boiled in a day when the juice and syrup purities are high. The schemes of three and four massecuite boilings are schemetically represented in figure (p. 313-314) Nevertheless the three massecuite system is more common and universally adopted.

In modern processing practice no new nucleation takes place in grain development or preparing footing as the graining method is based on feeding of fine sugar slurry and consequently fine grain is developed to bigger size in every type of massecuite i.e. A to C.

4. GRAINING

The term graining indicates establishment of grain footing for any boiling, containing the sugar grains of right size and sufficient number, employing one of the following three methods:

4. Waiting—In this method, which has been abandoned long ago the syrup or any liquor is concentrated until labile zone of supersaturation is reached when fresh nuclei of sugar
are formed. An indication of this state of supersaturation is obtained by taking sample of thick syrup from the proof stick between thumb and forefinger and forming an unbroken, long string of the viscous syrup, which serves to guide the panman. In the labile zone with degree of supersaturation of 1.6 and above rapid formation of fine grain takes place and the required quantity of grain is determined by the experienced pan boiler. When as per his judgement sufficient grain is established he arrests further grain formation by giving charge of water or lowering the vacuum by 7-10 cms. which results in increasing the temperature of the strike. Thereafter the concentration is maintained in metastable zone for allowing the grains formed to develop. Water drinks are given for nearly half an hour for hardening the grain which means developing the sugar grain to definite size. Hardening is followed by regular drinks of syrup or molasses as the case may be. This method is entirely dependent on the skill and personal judgement of the panboiler.

4.2. Shock seeding—This shock method of graining, which marks a distinct improvement over the previous waiting method, requires the concentration of the graining medium upto metastable zone. Finely ground white sugar (about 400-600 gm.) is charged into the pan, the supersaturation state being slightly above metastable zone, somewhat in the intermediate zone. Without instrument control the proper time for giving the powered sugar shock is determined by experienced panman by stretching the viscous syrup between his thumb and forefinger. When the length of string is about 2.5 - 3 cms. the stage is reached for charging sugar dust powder which is sucked in the pan through a funnel. In this system the particles of sugar do not serve as nuclei but serve as shock for inducing new grain formation at lower supersaturation than in the waiting method. If the shock is given before the proper supersaturation level is reached, the grain may not appear or may be too inadequate and if it is given late conglomerate formation and a mixture of different crops of sugar grains will appear. After the required amount of grain appears, the supersaturation is brought down to metastable stage by starting drinks of water or raising the temperature of pan by reducing the vacuum. This way further new grain formation is checked and then follows hardening of grain, by taking water charges intermittently. Some time gap is maintained between the shock seeding and starting the water charge as it takes some minutes for sufficient grains to appear, which is dependent on the judgement of the experienced pan boiler.

In both the methods it is essential to maintain concentration after arresting the grain formation, in metastable zone, allowing the grain to develop and higher concentration of the contents of pan has to be avoided as otherwise conglomerate formation will take place, a situation which cannot be rectified without dissolving the entire grain. Both these methods can be practised only by skilled and experienced pan boiler. Slight error of judgement with regard to—

(i) optimum concentration or

(ii) time of taking charges of water for arresting the grain will result in poor quality of grain with uneven size or of insufficient quantity. Even inspite of providing sufficient instruments the graining by these methods to a large extent has to depend on human judgement with the result that uniformity of results in respect of the size, quantity and quality of grain which have a great bearing on the performance of the panboiling is not assured.
4.3. True seeding method—

4.3.1. This method introduced in the fifties envisages no nuclei formation but instead developing fine grains furnished by slurry containing fine sugar and non aqueous solvent. The weight of sugar in slurry to be fed to pan is determined from the ratio of weight of a given number sugar grains of unit volume of strike to that of equivalent number of sugar grains in slurry for which it is necessary to find out—

(a) weight of sugar per cubic meter of massecuite in Kg.
(b) weight of 500 sugar grains from the massecuite in gms.
(c) weight of 500 sugar grains from the slurry in gms.
(d) final volume of strike to be boiled m$^3$

Weight of sugar in slurry is found out from

$$\frac{d}{a} \times \frac{b}{c}$$

The syrup or A heavy or mixture of both is boiled in the pan to supersaturation of 1.1 or 1.2 depending on the purity of medium and the slurry is introduced. Thereafter care is taken to see that at no stage is the supersaturation degree exceeded. For hardening the grain intermittent charges of water are given until the grain is hard and this is followed by intake of molasses for building up footing.

4.3.2. Methods of preparing seed slurry—The medium for seed slurry is some organic solvent which has lower boiling point than water so that the solvent explodes on entry into pan, whereby the sugar particles get distributed in the supersaturated syrup or molasses. The solvents suggested or used are—

(i) denatured ethyl alcohol,
(ii) Isopropyl alcohol
(iii) mixture of ethyl alcohol and glycerine
(iv) Gasoline.

For preparing a litre of slurry a ballmill of about 22 cms. diameter is required revolving at 60-65 rpm. in which are used steel balls or pebbles for grinding the sugar. Honig recommends use of 500 gms. of 18-20 mm. dia steel balls or pebbles per litre of volume of the jar which is usually twice the volume of seed slurry. The procedure for making slurry will be—

(a) to take weighed amount of white crystal sugar of high purity,
(b) transfer it to the ball mill jar along with solvent-preferably ethanol and
(c) then close it after inserting the balls.

The time of grinding will vary from 8 to 36 hrs. depending on the types of balls and initial sugar grain size but it is desirable to determine at each factory the time of grinding by actual trials, for getting $5\times$ size sugar particle.
4.3.3. Different methods of slurry preparation—

(i) Gillett who originally introduced full seeding method proposed the use of finely ground C & H. icing sugar and medium of isopropyl alcohol. The amount of sugar according to his work was 8 Oz of icing sugar per 1000 cuft. of C massecuite.

(ii) John Saint and Frank Hutchins; as a result of their investigation in Barbados prepared slurry in horizontal ball mill 16 cm. in dia. and 18 cm. long in which 2550 steel balls of 10 mm. dia were used. 800 gms. of special sugar were ground in 2200 ml. of methylated spirit, in the ball mill running at 60 rpm. for seven hours. The slurry contained sugar grains of 7 micron size.

(iii) Payne advocates the grinding of 1000 gms. of sugar in 2 litres of isopropyl alcohol in a jar mill of 4 litres capacity in which are inserted 4 kg of 20 x 20 ml. cylinders. This gives a slurry with 4.5 micron size sugar particles.

(iv) Appleboom developed use of fondant sugar for seeding in alcoholic suspension. In this method a solution of 500 gms. of sugar of 99.5 purity at 60° Bx is filtered and boiled to 118°C to give 82° Bx. To this solution is added 140 gms. of invert sugar solution made by inverting 1000 gms. of refined sugar in 282 ml. of distilled water. The mixture is cooled and thoroughly homogenised by agitation. The resulting fondant sugar is mixed with alcohol in the proportion of 200 ml. of alcohol and 100 gms. of fondant sugar solution, Thorough homogeneous mixture of alcohol with fondant sugar is obtained by stirring in a ball mill, 40 to 50 ml. of this slurry is to be used for 100 cuft. of seed strike. Honig however has expressed reservations about the uniformity of grain size of seed slurry as also some details of the procedure.

(v) In Java method 140 gms. of sugar are ground in 250 ml. of gasoline in a 500 ml. pyrex bottle with 80 nos. of 12 mm dia steel balls for 24 hrs. and this was sufficient for 3600 cuft. (101.9 m³) Strikes, the average grain size of slurry being 3-5 microns.

(vi) In yet another method the seed is prepared for high grade boilings by adding 1600 gms. of sugar to 3.3 litres of mixture of 70% methylated spirit and 30% glycerine and grinding in slurry machine running at 200 rpm. for 15 hrs.

(vii) In India S.C. Gupta and others prepared seed slurry in a porcelain jar ball mill containing 150 porcelain balls in which are ground 600 gm. of white sugar with 3 litres of Shell vitrio oil. Slurry containing 5 micron size sugar grains was obtained by running the ball mill at 65 rpm. for 32 hrs. Trials of this slurry were conducted in different factories with good results.

S.C. Gupta and S.K.D. Agarwal developed a method of preparation of slurry by precipitating sucrose from supersaturated solution. Supersaturated solution of sugar was prepared by dissolving 28 gms. of sugar in 10 ml. of water at 70°C, 100 ml. of rectified spirit is taken in a horizontal ball mill and to the running ball mill is added hot solution through a funnel. The ball mill is run for 30 min. for getting precipitate uniformly distributed in spirit. The slurry was taken out and supernatant clear liquor was replaced by fresh alcohol. This mixture was run in ball mill for 10 minutes. To the resultant slurry 30 ml. of castor oil is added for storage. 2. gms. of sugar is used
per tonne of massecuite for seed preparation with this slurry referred to as Alpre’s slurry. When used on large scale it gave uniform grain of C massecuite, and better exhaustion of molasses was obtained.

5. GRAIN ESTABLISHMENT

Whichever method of slurry preparation is followed it is important that in the seeding method of grain establishment it is the sugar grains in slurry which are allowed to develop and no nucleation is induced at any stage. In white sugar manufacture grain is made for B & C massecuites and A heavy molasses is used as medium in B massecuite boiling while grain for C massecuites is made in either A heavy of 72-75 purity or in a mixture of A heavy and B heavy of 60-70 purity.

After pan discharge valve is closed and vacuum of 635-660 mm. attained molasses of the desired purity is let in till the calandria is covered and concentrated to around 1.2 supersaturation degree. The slurry is fed through a special funnel fitted to the bottom of pan or feed pipe. The funnel is provided with lid and cock, which is opened gradually to admit seed slurry, care being taken to prevent air getting sucked in the pan. For hardening the grain best way is to use condensate from the calandria of the pan in which graining takes place, for maintaining steady rate of evaporation as also to avoid fluctuations in the concentration of medium. Within 10-20 minutes the grain becomes visible and after the seed grain has grown to a certain size the molasses feed to the pan can be started. It needs to be emphasised that the method of establishing grain should be standardised for both B and final massecuites, with the help of conductivity meters.

For graining A heavy is preferred to syrup, for preparing seed footing for B boilings and B heavy sometimes mixed with A heavy for C footings. This is in accord with the practice established first by Gillett and subsequently by many other investigators in India and other countries. Compared to high purity medium like syrup, advantage of low purity medium like A heavy lies in the fact that the sugar crystals developed are more uniform in size and free from conglomerates or twin crystals.

6. PRACTICE OF PAN BOILING

After the pan washing is completed, discharge valve is closed and vacuum developed by opening the condenser water valves. Simultaneous with vacuum reaching the desired level of 635-660 mm. the syrup intake starts till calandria is well covered and steam valve opened. Syrup concentration is followed by opening of seed crystalliser valve and the cut over line valve of the pan. After taking the required amount of seed next operation is to wash the seed, with either diluted syrup or water to dissolve fine grains. Thereafter the feed rate of syrup, A light and melt is so maintained as to keep pace with growth of sugar crystals. The rate of evaporation in the beginning is high and as the strike level goes up, it gets gradually reduced. The evaporation rate can be controlled by adjusting steam valve or the liquor feed, without disturbing the vacuum care being taken to see that the supersaturation does not exceed the limit when false grain starts appearing.
In the beginning of the cycle of boiling the volume of syrup or molasses is much higher compared to the volume occupied by crystals but as boiling proceeds and strike level goes up as a result of the crystal growth the void between crystals filled by mother liquor is reduced. When the pan is filled to the highest level, the crystals have grown sufficiently and feed is stopped for final tightening. The evaporation is allowed to proceed thereafter until the desired brix is reached. Rough guidance is provided regarding the final brix to the pan operator by taking out the sample of massecuite from the proofstick and observing nature of the thick mass and its fluidity. A ball of massecuite is formed on holding it in hand between thumb and palm, and how soon it gets flattened provides idea regarding brix reached. A better way is to use set points of supersaturation or conductivity readings or the load on motor of mechanical circulator indicated on ammeter if circulator is provided, for knowing the appropriate thickness of massecuite for discharging the strike. These set points of instruments are determined often on the basis of practical experience.

7. DISCHARGING THE PAN AND PAN WASHING

7.1. When the strike is ready for dropping into crystallisers the condenser water is stopped and vacuum breaking valve opened followed by opening of the discharge valve. The massecuite flows into a gutter positioned below the pan and connected to the different crystallisers. After the strike is discharged and pan emptied it is necessary to steam the inside of the pan to remove the massecuite adhering to the inside of the pan before commencing the next cycle of boiling. Live steam of 2.5 kg/cm$^2$ pressure is admitted into the circular pipe, with number of openings, located inside the top part of the pan for dissolving the crust and adhering massecuite while the washings are let out through the discharge valve of the pan. Yet another method preferred to the live steam washing is to use high pressure hot water spray directed towards the periphery of the inside of the pan, which will cause less colour formation. Recent practice is to use exhaust steam or vapours from evaporator for washing the pan. In accordance with the new method of exhaust or vapour washing the total cycle from pan dropping to restarting involves the following sequence of operations—

(i)  vapour or steam inlet to calandria is closed
(ii) condenser water flow stopped by closing water valves,
(iii) Pan wash out steam or vapour valve is opened,
(iv) discharge valve is opened,
(v)  after discharge of strike the bottom valve is closed
(vi) The pan washing valve is closed,
(vii) Condenser water is started by opening water valves,
(viii) Pan restarted for new boiling by drawing in fresh material.

When pan discharge valve is closed while the exhaust steam is still passing through it
and the condenser water is started, the steam is condensed in the pan helping to restore vacuum quickly.

This procedure involves 50% less loss of time as compared to the conventional method of use of vacuum breaking valve coupled with live steam washing. With the method described earlier the loss of time from end of one strike operation till commencement of new cycle is around 10-15 minutes for high grade boiling pan and less than 30 min. for final massecuite strikes, the reduction in the time loss being mainly attributed to quick raising of vacuum in the pan.

7.2. Disposal of washings—the panwashing in white sugar manufacture contains more colour than the massecuite to which they belong. Investigations by D.P. Kulkarni\textsuperscript{14} and others have shown the colour of A pan washings to be 93% higher than the colour of A massecuites while corresponding colour increase is reduced from A to C massecuite. Compared to this, the colour increase in washing pans for raw-sugar production was much less. The method of washing the pan consisted of spray of high pressure hot water at 75°C followed by steaming for 5-10 minutes using 2.8 kg/cm\textsuperscript{2} pressure steam of 130°C the temperature of washings collected being about 75°C

Usually the washing of pan are let into the same strike which dilutes the massecuite to some extent. In the case of C or final massecuite this is certainly not desirable and to overcome this problem the author had introduced the separate collection of washings to be mixed with C light molasses for use in 'C boiling.\textsuperscript{15}

8. USE OF CHEMICALS

Hydrosulphite of Soda Na\textsubscript{2}S\textsubscript{2}O\textsubscript{3} has been used since long in all boilings. This chemical releases SO\textsubscript{2} which has a bleaching action and helps reduce the colour of the massecuite. It has been a common practice to add it to A pans as it is a strong reducing agent and is expected to improve whiteness of sugar. But the bleaching effect is short lived and on re-exposure, the substances formed as a result of action of Na\textsubscript{2}S\textsubscript{2}O\textsubscript{3} get reoxidised. Its role on reducing viscosity of C massecuite is also questionable.\textsuperscript{16}

Surface active agents have the property of reducing surface tension in liquids or interfacial tension between two liquids and are classified as anionic, cationic or nonionic depending on the charge. These chemicals are of high molecular weight manufactured from organic compounds. They have been found to reduce viscosity in boiling viscous massecuite and are being widely used in C massecuite boiling to bring down viscosity and thereby improve exhaustion of molasses. Their additions to all A, B and C massecuite boilings in the pan have been reported to produce good results in respect of molasses exhaustion, in one Indian factory.\textsuperscript{16}

9. THREE OR FOUR MASSECUITE SYSTEM

9.1. It is always desirable to have less stages of boiling without resorting to recirculation of nonsugars i.e. putting back low purity material in the boiling process and therefore every
endeavour is required to manage with three stage boiling i.e. three massecuite system by
achieving maximum exhaustion in the pans and crystallisers as also by rigid control over
washing in centrifugals. Nevertheless when the juice purities rise to 85-86 during the
period of peak recovery, when the cane has reached full muterity it may not be possible
to manage within three stage boiling without increasing sugar loss and intermediate
stage between B & C will hve to be introduced which we shall term as Bl. Both the three
and four massecuite schemes for good quality white sugar manufacture are presented
below—

9.2. Three massecuite system—Syrup purity 80-82.

A Massecuite: White seed + Syrup + AL + Melt from washed 'C sugar and partly B
washed-sugar——-> Purity of Massecuite 85-86. Purity of A heavy
68-69.

B Massecuite: Grain from A heavy and B light for 3 pans + A heavy of 68 purity —
——> Purity of massecuite 69 to 71. B heavy purity 48-50.

C Massecuite: Grain in B heavy + A heavy for 3 pans + C light + B heavy.

C Massecuite of 53-54 purity

C light of 56-58 purity.

9.3. Four Massecuite System—Syrup purity of 85-87.

A Massecuite : Seed + Syrup + A.L. + Melt——> A Massecuite of 87-89 purity. On
curing A heavy purity 71-73.

B Massecuite: Grain on A heavy and B light for 3 pans. Footing + AH——> B
Massecuite of 73-75 purity on curing B Heavy purity of 50-53.

Bj Massecuite : Footing from B vacuum crystalliser Bx light and B Heavy——> Bj

C Massecuite: Grain on B heavy + C light for 3 pans. Footing + C light + B heavy + Bx
heavy——> C massecuite of 53-55 purity.

9.4. Schematic diagram gives an idea of the above two schemes of boiling. In both the systems
following steps are necessarily adopted for producing bigger grain sugar of good quality.

(a) C massecuite is double purged and well washed sugar is melted, the melt being used
in A boiling.

(b) Seed for A boiling consists of white fine sugar from sugarhouse to be supplemented
by magma made out of well washed sugar from double purged B massecuite, surplus
'B' sugar being melted.

(c) Grain is made by seeding method.

(d) As we proceed from A massecuite to final massecuite boiling the mother liquor
purity goes down and rate of deposition of sucrose from the mother liquor on the
sugar crystals gets gradually reduced and higher supersaruration has to be
maintained with the result that the boiling becomes slower and the time of boiling
strike increases. Thus if A strike takes 2-1/2 to 3 hrs. for C massecuites 7 to 8 hrs. are required in a pan without mechanical circulator.

10.

10.1. The functions of the entire crystallisation station i.e. pans, crystallisers and centrifugals have to be properly organised for smooth operations as far as systems of boiling are concerned and therefore the equipment and operations of crystallisers and centrifugals are to be geared to efficient pan operations. The operations at crystallisers and centrifugals in modern plants are as under—

10.2. A Massecuite—A massecuites dropped in air-cooled crystallisers are cooled to 50°-55°C and purged in centrifugals applying steam and water wash or superheated water wash. The light and heavy fractions of molasses are separated as A heavy and A light. Both single and double purging systems are in vogue. The white sugar is dried on hopper and passed through grading screens the fine sugar below 0.5 mm. being usually made into magma and sent to pan-floor for use as seed.

10.3. B Massecuite—B massecuites are cooled in crystallisers to 45°-50°C and cured in continuous centrifugals or high gravity batch machines. When the B sugar is to be used as seed, the massecuite should be double purged, so as to prevent small quantities B heavy molasses going to A boiling, the light molasses being separated for use in B boiling. When the B sugar is not required as seed on pan-floor it is made into magma and pumped to melter.

10.4. C Massecuite—These are double purged and the sugar melted. The light and heavy molasses are used in C boiling. Cx massecuites need not be cooled much but cured in continuous centrifugals.

10.5. C Massecuite—The C massecuites are cooled in crystallisers with cold water circulation, through the coil type stirring elements to 40°C and then reheated to 50°-52° before being purged. Double purging of C massecuites is absolutely essential, the molasses from first curing being thrown out of the process as final molasses. In the second purging, with application of hot water wash the adhering molasses along with dissolved sugar is pumped to panfloor storage tanks as C light molasses to be boiled again in C strikes. The sugar after second purging is dissolved in a melter and melt used in A boiling.

The quality of melt needs special attention as the melt is fed to A boiling invariably and if the sugar that is melted is not properly washed it would be accompanied by low purity C light or B heavy, the material which contains very high colouring matter.

11. TECHNICAL RECORDS

It is good practice to draw graphs of each pan operation as the graphical representation of working of every pan serves to guide the skilled pan operatives as well as the technologists regarding—
(a) capacity utilisation,
(b) loss of time
(c) coordination of working of pans, crystallisers and centrifugals.
(d) time taken for each strike.

Separate technical control books for pans and crystallisers are maintained containing the technical data about each strike from start to end of purging. Lacunae in operations or coordination of working of the three stations viz. pans, crystallisers and centrifugals can be removed and working improved by maintaining these records and carefully studying them every now and then.

CONTINUOUS PAN BOILING

1. In the past six decades vigorous attempts were made to introduce continuous operations at various stages of the process of sugar manufacture. At the crystallisation stage continuous crystalliser and centrifugal operations were established much earlier but continuous pan boiling posed problems in the initial phase of development mainly in respect of—

(i) uniformity of crystal size
(ii) circulation of mass
(iii) constant displacement of bigger size crystals by smaller ones,
(iv) increase in viscosity with gradual exhaustion of mother liquor.

However these hurdles were overcome in the past few decades and continuous pans were first established in beet sugar industry as well as sugar refineries where the conditions were favourable for their introduction due to high labour and fuel cost. In cane-sugar industry Fives Lile established their continuous pan design in Reunion and similarly in South Africa, Queensland new continuous pan designs were subsequently introduced.

2. Continuous pan boiling application to plantation white sugar production is being introduced gradually in Indian Sugar Industry, wherein the following special features of the process have to be kept in mind:

(i) In some parts of India the market prefers bold gain sugar of the size of 1.2 to 2 mm. and production of big crystals is invariably accompanied by manufacture of different sizes of grains, though attempts have to be made to produce big grains of uniform size,

(iii) In view of the use of melt from low grade boiling, in the boiling of A pans, from which marketable sugar is produced, the purities of A massecuites vary from 87-90 and exhaustion of mother liquor assumes special importance,

(iii) To achieve low purity of final molasses, final massecuite purities have to be brought down to 50.0 or even lower which necessitates frequent boilings of an intermediate
massecuite between B and final massecuite. Against this background the requirements of a proper system for continuous pan boiling will be

(a) shorter duration of crystals in pans,

(b) no stagnation of mass as it would lead to undesirable results like development of colour, inversion and high coefficient of variation of sugar crystal size.

(c) maximum concentration of massecuite at the discharge point for proper exhaustion.

(d) footing will have to be prepared in different batch or continuous pan for final massecuite and even for intermediates massecuites for which adequate provision has to be made.

3. DESIGN ASPECTS

The popular design which have been established in cane sugar industry are characterised by certain common features such as—

(a) multicompartment system, consisting of 6 to 14 cells, interconnected, each cell being a tubular or plate type calandria.

(c) high heating surface to working volume ratio (10 mVm$^3$) nearly 1.8 to 2 times that obtained in batch pans.

(c) low height of boiling mass, 0.13 to 0.5 m above top tube plate of calandria.

(d) common vapour withdrawal, which ensures constant and same vacuum for all compartments.

(e) continuous feeding of 'seed' footing, prepared separately in batch or continuous pan.

(f) automatic control of—

(i) steam pressure and vacuum,

(ii) feed of syrup or molasses or seed

(g) plug flow of mass throughout the system.

Initial endeavour towards evolving designs for continuous pan, centred around final 'C' boiling since difficulties are experienced in case of 'A' boiling in controlling the C.V. of sugar crystals, which has special significance in raw sugar production. Low pressure steam of 0.2 to 0.4 kg/cm$^2$ can be employed for any type of boiling and in order to achieve constant output rate, it is desirable to avoid variations in brix of feed of syrup or molasses. Continuity of flow of mass from one end to the other together with continuous feed and withdrawal are the essential pre-requisites of continuous pan operation which make it obligatory on the factories to arrange for suitable capacities for storage of syrups, molasses and massecuites.

Lithium tracer studies, which throw light on the nature of flow, whether it approaches
plug flow, conducted in south Africa\textsuperscript{23} and Australia\textsuperscript{19} have shown the respective designs to be satisfactory, from the point of residence time of crystals, which has a bearing on size distribution of grains.

4. SALIENT FEATURES OF SOME DESIGNS

4.1. As a result of research work carried out during sixties, Fives Lilie-Cail of France developed a continuous pan which was established in Beet sugar industry and sugar refineries in the late sixties. Later on the first continuous pan in cane sugar industry was commissioned in Reunion, by this firm in the early seventies\textsuperscript{17}. This was a horizontal cylindrical pan of stainless steel construction, with heating surface provided by hollow vertical platelike elements. The cylinder is divided inside by partition plates into 4 to 11 compartments depending on the type of strike and whether pan footing is introduced from outside or the pan is to be used for seeding to discharge stage. A lengthwise partition is inserted from one end to the other. The height of partitions is about 50 cms. above the level of massecuite which prevents intermixing of boiling mass of adjoining compartments. The magma is fed to the first compartment and the arrangement of partition plates is such as to allow massecuite to travel from the first compartment to the successive compartments through orifice openings at the bottom. Syrup or molasses is introduced in each compartment and thus the massecuite as it moves from the feed end, receives feed for maintaining the required supersaturation of mother liquor.

The heating surface to volume ratio is 10-12 m\textsuperscript{2}/m\textsuperscript{3} of massecuite and the massecuite level is maintained 50-80 cms. above the top of heating elements which are more or less similar in construction to those in the batch horizontal pan but with extended lengths. The syrup or molasses is added at the entry into each compartment, the flow being controlled with the help of flow-meters. The vacuum in the entire vessel is the same.

The control instruments employed are—

(i) vacuum controller,

(ii) vapour pressure controller,

(iii) Supersaturation controller,

(iv) footing volume controller.

4.2. In the later tubular version of this design\textsuperscript{18} the heating surface is made up of bank of horizontal tubes arranged in vertical rows, running the entire length of the cylindrical vessel, and leading to steam boxes on the end faces. One longitudinal partition plate and other at right angles to the axis of the cylinder divide the pan into suitable number of compartments connected to each other by orifice like openings at the lower part of partition plates.

The principle accessories include—

(i) entrainment separator,

(ii) manhole
(iii) sight glasses

(iv) vacuum breaker,

(v) sampling cock,

(vi) pressure and vacuum as well as thermometer gauges.

Hugot reports boiling of tight 'C massecuites with these pans with final molasses giving 0-2 unit lower purity than with batch pan.

4.3. In the continuous horizontal pan developed by the Sugar Research Institute of Mackay Australia, multicellular system is adopted with each cell consisting of tubular calandria. The pan for C boiling has a heating surface to volume ratio of $10 \text{m}^2/\text{m}^3$ and nearly 90% vapour space. The level of boiling strike is 20 to 40 cms. above the top of calandria and syrup or molasses feed is provided in each cell at the bottom of the pan through branched pipe work. In the floating type calandria arranged separately inside the pan, the top tube plates are sloping towards both sides. In the seven compartment pan at Tully, massecuite passes between compartments through the openings below the calandria. Internal partitions located across the longitudinal path of boiling massecuite retard the movement of massecuite along the calandria. Provision is made to inject steam at the bottom near the molasses feed entry. Crystal incrustation is sought to be minimised by coating the upper wall surfaces with epoxy paint.

The control system incorporates regulation of—

(a) vacuum

(b) feed control by conductivity transducers in each cell

(c) steam flow

(d) seed inlet by control of pump speed,

(e) level of massecuite inside by adjusting overflow weir.

In low grade boiling seed is of purity 67 and crystal content 25.

4.4. In the continuous pan design for high grade boiling two modules are provided each one containing separate calandria, and the pan is divided into nine cells, with each one being fitted with conductivity electrodes and proof stick for drawing sample. Feed system and all other design features are similar to the low-grade pan. Evaporation rate of 10.5 to 17.5 kg/m$^2$ per hr. was obtained at Maryborough factory.

4.5. The B.M.A. continuous pan known as Evapocrystallisation tower, is vertical in construction, with crystallisation chambers superimposed over one other, wherein the massecuite flows by gravity from top chamber to bottom. Stirrers have been provided in all chambers, and the stirrer speeds are reduced from 112 rpm. in top chamber to 30 rpm. in the lowest chamber. The controls for level, feed, speed of discharge massecuites pump, seed flow rate and density are provided for the pan.

4.6. In another horizontal design of continuous pan introduced in Reunion by Langreney, the heating surface to volume ratio is around 10.0 m/m$^3$. Two semicylindrical bottom-plates
and two vertical side plates have been provided for the tubular calandria. Feed is delivered at the bottom of calandria through two feeding mains and separate feed connections positioned every 25 cms. alongside the pan wall. Footing is introduced at one end of the pan by means of variable speed pump while the massecuite outlet through the weir at the other end maintains constant level. According to the author of the design it is possible to boil 'C' massecuites of lower purity compared to conventional batch pans and this pan is suitable for all stages of boiling viz. A, B & C.

4.7. The continuous pan developed at Tongatt in South Africa is divided into 12 compartments and incorporates a vertical tube calandria fitted with tubes of 100 mm. dia and 1.5 m. height. Molasses or syrup is fed to each compartment below the calandria and jigger steam connections have been provided for each compartment which are normally controlled. In yet another design the tube height is reduced to 1.45 m. for B and C boilings and 1.3 m. for 'A' boiling pan. Entrainment separator and condenser form internal parts of the pan. Massecuite flows from one compartment to another through ports located immediately above the calandria to avoid incrustation and ensure plug flow.

The controls are based on conductivity capacitance and B.P.E. measurements. The 'A' pans are emptied after two weeks and water boiled for removing crust formed. The calandria steam pressure is about 0.5 kg/cm$^2$ and specific evaporation coefficient of 9 kg/hr/m$^2$ is reported. The continuous pans have been installed for all A, B & C boiling.

Indian Pan—The continuous pan developed by M. Anand at Ponni Sugars Ltd. India is horizontal in construction with rectangular calandria provided with a centrally located channel serving as downtake. The pan is divided into seven compartments for boiling 'A' massecuite. Vapours from first body of evaporator at 0.15 to 0.2 Kg/cm$^2$ pressure are used for boiling 'A' strike. The level of massecuite is about 1.0 m. above the top tube plate of the calandria with tube height of 1.0 m. In 'A' Boiling the seed size of 0.35 mm. increases to 0.70-0.75 mm. at the discharge end. Satisfactory performance has been reported in respect of circulation, crystal development and exhaustion in the pan, with 'A' massecuite boiling at Ponni Sugars.

5. PROBLEMS AND ADVANTAGES

5.1. Any continuous system of process operation presents certain problems and pan boiling cannot be an exception to it. The problems faced or associated with continuous pan boiling are—

(i) Sugar crystal incrustation formed on surface is a serious problem particularly with high grade boiling. In Australian pan the crust of 50 mm. thickness was found at the end of four weeks' operation of 'A' boiling on the steel surfaces. The crust development is sought to be reduced by spraying of feed liquor on the exposed surfaces and providing heating jackets to the underside. Fine water sprays are also applied to internal surface and in South Africa continuous pans are cleaned after two weeks of operation.
(ii) In high purity boilings crystal size variations are pretty high.

(iii) Seed footing has to be prepared in separate pan and whenever pan is to be emptied, the contents have to be boiled in batch pan.

(iv) In the event of sudden breakdown the entire boiling mass has to be drained from high grade pans, further processing of which would be difficult.

(v) In white sugar boiling sometimes the sugar from certain strikes boiled in conventional batch pan is below the required quality standards and is then, separated from the other bulk of sugar produced for reprocessing. This will not be possible in continuous system and in all likelihood, much larger quantity of sugar will get spoiled as no rectification is possible in continuous working.

5.2. Advantages—

(i) For the same nominal volume the capacity of continuous pans is about one and half times that for batch pans.

(ii) Low pressure vapour from evaporator can be more effectively used without fluctuations in steam demand. The evaporator and boiler stations achieve steady-working without peaks and valleys in steam requirement. Evaporator from which vapours are drawn for pan boiling achieves steady working.

(iii) Better exhaustion of molasses has been achieved in continuous pans as compared to batch operation.

(iv) Greater uniformity in operation with respect to crystal size and exhaustion is obtained.

(v) Number of units like condenser and other pan ancillaries is reduced and thus maintenance cost is much less.

(vi) Continuous system lends itself well to control of operation.

(vii) Labour cost is reduced.

6. PROPORTIONS OF DIFFERENT MATERIALS FOR MASSECUITE BOILING

The method followed for arriving at different quantities of materials to obtain the strike of purity $P_3$ is as under—

$X_1 = \text{Quantity of footing or syrup by weight.}$

$X_2 = \text{Quantity of molasses to be boiled by weight.}$

$X_3 = \text{Quantity of massecuites to be boiled by weight.}$

$X_{b1} = X_{b2} \text{ and } X_{b3} \text{ indicate the brix or drymatter by weight in footing or syrup, molasses and massecuite respectively.}$

Purity of footing or syrup $P_1$
Volumes can be worked out by dividing the weights of different material by their respective densities. The calculations according to the above equation are quickly made by following Cobenz diagram as under

\[
\begin{align*}
\text{Purity of molasses} & \quad P_2 \\
\text{Purity of massecuite} & \quad P_3 \\
1. \text{Since purity} \times \text{brix} & = \text{Pol or sugar}.
\end{align*}
\]

\[
X_1b_1P_1 + X_2b_2P_2 = X_3b_3P_3 \quad \text{A}
\]

Similarly

\[
X_1b_1 + X_2b_2 = X_3b_3 \quad \text{B}
\]

and

\[
X_2b_2 = X_3b_3 - X_1b_1 \quad \text{C}
\]

Equation A will become

\[
X_1b_1P_1 + (X_3b_3 - X_1b_1)P_2 = X_1b_1P_3 \quad \text{D}
\]

\[
\therefore X_1b_1(P_1 - P_2) = X_3b_3(P_3 - P_2)
\]

\[
\frac{x_1b_1}{x_3b_3} = \frac{P_3 - P_2}{P_1 - P_2}
\]

In terms of quantities—

\[
\frac{x_1}{x_3} = \frac{(P_3 - P_2)b_3}{(P_j - P_a)P_1}
\]

Volumes can be worked out by dividing the weights of different material by their respective densities. The calculations according to the above equation are quickly made by following Cobenz diagram as under

If a massecuite of 55 purity is to be dropped from footing of 70 purity and feed molasses of 50 purity the proportions by weight of footing and molasses will be

\[
\begin{align*}
\text{Proportions of} \\
\text{Molasses} & \quad \frac{15}{20} = \text{Solid matter} \\
\text{Footing} & \quad \frac{5}{20} = \text{Solid matter}
\end{align*}
\]
REFERENCES

TYPICAL MODEL BOILING, CRYSTALLISATION AND CURING SYSTEM

Stage-1 Syrup purity 80-83 A Massecuite

Syrup + A light → A Massecuite → Batch aircooled Crystallisers
+ Melt + Seed

Py
(i) White sugar bagging
(ii) Fine Sugar
(iii) as seed

oversize melted

(i) A Heavy molasses
(69-70 purity)
(ii) A light molasses 90 Py

Stage-2 B Massecuite

Grain in A.H. Py 70 → Vacuum Crystalliser

Centrifugal ← Water cooled crystalliser

Sugar (96 Py)

B Heavy (Py 48-52)

Used partially as seed for A boiling and remaining melted

Stage-3 C Massecuite

Grain in AH & BH → Vacuum Crystalliser → Pan ← B Heavy

Continuous receiver ← C Massecuite Py 54-56

Cooled to 40°C
heated in reheater

Centrifugals for purging
double → Final Molasses Py 28-30

C light 56-58
Sugar melted
II
FOUR MASSECUIE BOILING : SYRUP PURITY 85-87

1 'A' Massecuite

| Syrup 85-87 | → | Pan 'A' | → | A Massecuite | → | Aircooled | → | Centrifugal |
| + A Light | + Melt | | | Py 87-89 | Crystalliser | | ↓ | ↓ | Alightly-90 |
| | | | | Vacuum | grain | ← | A Heavy | A heavy of Py 72-73 |
| | | | | Crystalliser | | | (i) Sugar for bagging |
| | | | | | | (ii) Fine Sugar for seed |
| | | | | | | (iii) Lumps oversize melted |

2 'B' Massecuite

| Grain from vacuum | → | Pan | → | B Massecuite | → | Water cooled |
| Crystalliser | | | | Py 74-75 | Crystalliser | |
| B Heavy | ← | Centrifugals | ↓ |
| Py 52-53 | | | |
| (i) Sugar for seed |
| (ii) Excess melted. |

3. B1 Massecuite

| B Heavy | → | Pan for grain | → | Grain | → | Vacuum crystalliser | → | B1 Pan | ← | B heavy |
| B1 Molasses | ← | Centrifugal | ↓ |
| Py 40-43 | ← | air cooled crystalliser | B1 Massecuite | | | Py 58-60 |
| Sugar melted |

4. 'C' Massecuite

| Grain from vacuum | → | C Pan | → | C Massecuite | → | Receiver | → | Continuous crystalliser |
| Crystalliser | | | | Py 50-52 | | | ↓ |
| C1 molasses | ← | Centrifugals | ↓ |
| C Light | | | Reheater |
| Py 26-30 | | | Sugar melted |
| | | | C Light from double purging |
1. CRYSTALLISERS

Function—The massecuites boiled in pans are discharged into open mild steel vessels, fitted with stirrers, known as crystallisers. In the pans by concentration of the mother liquor to high supersaturation levels, maximum crystal development is accomplished. In the second phase of crystallisation, further desugarisation of mother liquor surrounding the sugar crystals is sought to be achieved by cooling in the crystallisers in accordance with the principle that supersaturation of sugar solution increases on cooling, and the massecuites dropped from pans at 70-75°C are cooled to temperatures from 40° to 55°C, lowest temperature being advocated for final massecuites. Gradual lowering of temperature results in reduction in the solubility of sucrose in the mother liquor with consequent deposition of sucrose on the existing crystals. The cooling of massecuite takes place in two ways in the crystallisers: One is air-cooling i.e. in crystallisers with simple agitators and second, water cooling in crystallisers with elements through which cold water is circulated. As the massecuite gets progressively cooled the viscosity increases and the stirring elements as also the driving mechanism have to be sturdy to cope with the increasingly viscous massecuite. In low grade massecuites particularly, viscosity assumes special significance in respect of the design of the crystallisers in which cooling is effected by circulation of water through the agitators.

2. LOCATION

Logical location of the crystallisers should be below the pans, and the massecuite from the crystallisers should flow by gravity into centrifugal pugmills for which the pans are installed on a supporting structure nearly 12-14m. above the ground floor of the factory while the crystallisers are positioned nearly 7-9m. above ground floor to facilitate flow of cooled massecuites through sloping gutters to the centrifugals pugmills. However in some plants, in the layout of the crystallisation station the pans are installed at a height of 8-10 m. while the crystallisers are on ground floor provision being made for pumping massecuites from crystallisers to centrifugal station. The only advantages with this layout of two storeyed structure are the reduction in cost of steel structure and comparative ease of supervision. But the disadvantages are

(i) pumping of cold massecuites or massecuites of high brix is extremely difficult and many times to facilitate pumping, dilution of massecuites is resorted to,

(ii) maintenance of pumps - mostly rotary pumps, increases extra work

(iii) power consumption of this station increases.

In view of the fact that disadvantages of the design of plant layout incorporating the crystallisers on ground outweigh the minor advantages associated with this system, it is recommended that the crystalliser floor must be installed at 7-9 m. above ground floor of
the factory with massecuite flow being arranged by gravity employing sloping gutters as this arrangement favours maximum recovery of sugar from every massecuite, thereby bringing down loss of sugar in molasses.

3. AIR-COOLED CRYSTALLISERS

These horizontal vessels of 'u' shaped cross section are made of M.S. Plates and fitted with slow moving stirrers to keep the massecuite agitation.

A shaft running through the entire length of crystallisers supports a spiral type stirrer with or without straight arms. The lowest portion of the spiral or arms never rub the crystalliser bottom maintaining a distance of about 15-20 mm. from the bottom. The stirrer rotates at about 1/2 r.p.m. and is driven by electric motor through a reduction gear, the installed power being about 8.5 h.p. for 45 T crystalliser or 15 h.p. for 65T crystallisers. The holding volume of each crystallisers has to be about 15-20% higher than the capacity of the pan which is going to be discharged into it and the sound practice is not to mix one strike from pan into other to avoid mixing of crystals of different sizes as also to complete proper cooling of massecuites. Crystalliser capacity should be based on

(a) time taken for the massecuite to be cooled to the desired temperature,

(b) time taken for completely emptying the crystalliser in curing

(c) total amount of massecuite to be dropped in crystallisers.

Thus by calculating the time-cycle for each crystalliser strike from filling to emptying and allowing for safety margin of 25% optimum capacity can be arrived at suited to each type of massecuite.

There is yet another type of air-cooled crystallisers in which the agitation is brought about by two helical stirrers rotating in opposite direction. The helical elements are mounted on two shafts one over the other in the 'U' shaped vessel. The upper stirrer has one-third its height above the top level of the massecuite. The drive for these stirrers is provided through two worm wheels from the same worm. As the upper helix by breaking massecuite surface, brings thin layers of massecuite into contact with air, greater cooling effect is achieved as compared to ordinary single agitator crystallisers and according to Hugot the cooling time is reduced by half that for ordinary crystallisers.

4. WATER COOLED CRYSTALLISERS

4.1. In crystallisers with fixed cooling elements, the sets of coils are positioned vertically at about 40 cms. distance. Each coil is connected to cold water inlet and warm water outlet pipes at the upper end. Massecuite is agitated by paddles rotating between successive coils. This type of cooling arrangement can be introduced in ordinary crystallisers but this design is no longer favoured as crystallisers with revolving cooling elements are installed in modern plants.

In the crystallisers with rotating cooling elements special feature of the design is that the
water is circulated through the stirring elements which are either coils or hollow discs. The cooling elements mounted on the central tubular shaft receive water through the central pipe of the shaft while the warm water flows back to the annular space between the central cold water pipe which is surrounded by the outer tubular pipes. Water inlet and outlet connections are on the same end opposite the drive end of the crystalliser. In general the heating surface to capacity ratio of water cooling crystallisers is maintained at 1-2.8m$^2$/m$^3$ volume of massecuite.

4.2. One of the most widely used water-cooling crystalliser is the Fletcher Blanchard design in which the revolving heat exchange surface is made up of a series of S’ shaped elements and straight tubes with closed ends, mounted on the central rotating hollow pipe. Different designs of cooling coils are available and in Five Lille type crystallises the cooling elements are either hollow plates or spiral plates.

In some crystallisers in place of coils different designs of hollow disc are employed for cooling and stirring as for instance in the Steams Rogers rapid cooling crystalliser the elements are fan shaped or hollow block elements attached to a central shaft through which hot and cold water are flowing. The crystalliser is designed for rapid cooling and reheating of all massecuite, with cooling surface to volume ratio of 5.3m$^2$/m$^3$ of massecuite.

4.3. Lafeuille crystalliser : Special feature of this type of crystalliser is that it is a rotary unit and can serve either as pan or crystalliser. This crystalliser is a large cylindrical vessel with its two circumferential rings resting on rollers. Stationary cooling coils of 5cm. dia are horizontally located extending the full length of the crystalliser to which cold water; hot water or steam can be supplied. Rotary motion of the crystalliser brings about proper agitation and thorough contact of massecuite with cooling or heating elements. The drum diameter is about 2.0 m and the length varies as per capacity. When used as pan it rotates at 1 r.p.m. but as crystalliser the speed is 0.25 r.p.m. The cooling surface to working volume ratio being around 6.5 m$^2$/m$^3$ thorough contact of the entire massecuite with cooling elements is ensured resulting in rapid cooling of massecuite. Work in Java has shown greater crystal yield coupled with lower molasses purity with Lafeuille crystalliser when the massecuite is rapidly cooled and stirred at ordinary temperature. With very low hydrostatic head it can efficiently cool the massecuite, giving a good purity drop. Moreover it occupies little space and consumes comparatively low power requiring 4 to 8 h.p. It is stopped while being filled or emptied. Main disadvantage with this crystalliser is that it cannot form part of continuous system as it is necessarily a batch crystalliser.

5. CONTINUOUS CRYSTALLISERS

5.1. These can be divided into two types viz. those which are designed as continuous crystalliser units and those which are composed of 4 to 6 batch crystallisers joined together and functioning as a continuous single unit. In the first category are crystallisers of Werkspoor and other designs.

5.2. Werkspoor—In this crystalliser, with a shell similar to ‘u’ shaped crystalliser hollow discs are attached to a central hollow shaft with water connections. Massecuite enters at one end
CANE SUGAR MANUFACTURE IN INDIA

continuously and overflows from the opposite side while cold water enters the cooling elements on the massecuite discharge end. In this way cold water will come into contact with massecuite which is cooled and will get gradually heated during its passage through the discs towards the massecuite entry end, by heat exchange with the hot massecuite. This counter current flow of massecuite and cold water to which it transfers its heat ensures minimum temperature difference between the water and massecuite eliminating risk of sudden increase in supersaturation and false grain formation. The cooling surface to volume ratio is about 6.5-9m²/m³ for 'A' i.e., for first massecuite but is brought down to about 0.9 m²/m³ for handling final or 'C' massecuites in view of the increase in viscosity, as also brix and impurities from 'A' to 'C' massecuites, which calls for slowing down heat transfer rate as well as the cooling rate. The heat transfer coefficients recommended by Hugot for Werkspoor in KCal/m²/hr/°c are 58.8 for 'A', 49.0 for 'B' and 19.6 for 'C' massecuites respectively. The power required is much lower than that for other types of water cooled crystallisers. Reheating of cooled massecuites can be accomplished after increasing length of the crystalliser by installing 3-4 closely spaced discs through which hot water is circulated.

5.3. Conversion of batch cooling crystallisers into continuous system—Werkspoor continuous crystalliser described earlier is a single container with all the cooling elements housed inside the shell. In the past three decades attempts have been made in different parts of the world to join a group of batch watercooled crystallisers so as to convert it into a continuous system in which the cold water flows in counter current fashion to the massecuite travel. The entire system comprises following units:

(i) Massecuite receiver which is an air-cooled crystalliser that can hold contents of one pan. Usually two such receivers are used.

(ii) Rota pumps to continuously transport massecuite from receiver to continuous crystalliser.

(iii) A group of water cooled crystallisers three to six in number usually preceded by air-cooled crystalliser unless the hot massecuite is to be rapidly cooled in which case the hot massecuite from receiver is pumped into water-cooled crystalliser.

(iv) Massecuite reheater which receives cooled massecuite through gutter connected to the outlet opening at the top of last crystalliser.

In the continuous crystallisation the crystallisers are inter-connected with each other in such a manner that the inlet and outlet of each crystalliser are on opposite ends. Suitable vertical baffles have to be positioned in the crystallisers to prevent channelling or local pockets of stagnant material. In modern systems it is possible to establish plug flow of massecuite and controlled cooling with good results as shown by studies conducted in Australia, India and other countries. Continuous crystalliser units composed of a group of air-cooled and water-cooled crystallisers lined up together have been found to be very helpful in the cooling of 'T' & 'C' i.e. last two grades of massecuites and reducing the quantum of massecuite boiling as also the loss of sugar in molasses. As for 'A' massecuites the system can be successfully employed in factories producing small grain white sugar of 0.6-0.8 mm. size.
6. As regards the design aspects of water-cooled crystalliser any design which takes into account the basic factor of the uniform cooling of entire mass of the container should be suitable, provided of course that the cooling elements, driving gear and shaft are sturdy enough to withstand the high viscosity of cooled massecuites. Some factories have experienced problems—

(a) of leakage developed in cooling coils,

(b) inadequate power and gear strength when low-grade massecuites of high brix of 100° and above are cooled. According to Bruyn revolving discs, particularly when mounted parallel to axis of rotation offers much lower resistance than revolving tubulour elements, for the same heat transfer.8

The speed of rotation will vary with the grade of massecuite, being higher for high grade massecuites but low in the case of low purity massecuites and it usually is maintained between 1.5 to 0.2 r.p.m. However the higher speed favours higher heat transfer from the massecuite to cooling water as shown by Honig,9 and thus it is important to maintain as high speed of rotation as practicable. The power installed for water cooled crystalliser with revolving cooling elements will be around 0.33 - 0.5 h.p. per cu.m. of low grade massecuite.

7. CONTINUOUS VERTICAL CRYSTALLISERS

7.1. In the last decade—continuous vertical crystallisers of different designs have been installed for cooling and reheating of 'C massecuites in Indian industry. The entire unit comprising one or two cylindrical vessels can be installed in short space and its components are—

(i) cylindrical vertical tank,

(ii) two sets of fixed cooling coils for circulation of cold and hot water,

(iii) Stirrer running throughout the vertical axis of the vessel consisting of paddles fitted to central shaft.

(iv) massecuite inlet and outlet troughs,

(v) motor drive through a gear mounted on top of the tank.

Most of the systems designed in India are equipped with straight tubes superimposed on one another which are sealed at appropriate ends and are provided with water connections. The paddles are so positioned as to scrape the cooling or reheating elements. In one design Werkspoor type closed discs are fitted as the manufacturers consider them to give higher heat transfer as compared to tubular cooling elements. In one case two vessels are grouped together, for completing the entire process of cooling and reheating of 'C massecuites. The vessels are about 6-9 m. in height depending on the hold up. The capacity of the crystalliser is decided on the basis of—

(i) total massecuite to be handled per day,

(ii) period of cooling of 12-14 hours followed by
7.2. Hugot has described at length the important features of the vertical continuous crystallisers manufactured by B.M.A. in Germany Seum and Fives Cail Babcock in France. These crystallisers are vertical cylindrical tanks of 8-12 mm. thick m.s. plate shell with diameters varying from 3.6 to 5.2 m. and 7 to 16 m. heights. In the French designs the shell incorporates 9 to 19 horizontal parallel pipes connected by 4 bends. To a vertical shaft are fitted horizontal stirrers with alternate stirrers at 90° to the neighbouring ones. In the French crystallisers the ratio of heat exchange surface to volume is 1.0 to 1.25 m$^2$/m$^3$ and in the F.C.B. equipment the speed of stirrers can be varied upto 0.6 r.p.m. In B.M.A. crystalliser, the cooling elements consist of discs covering 300-330° of circular portion in which proper circulation of water is ensured by vertical circular ribs covering major portions of the discs. The discs are connected by pipes and they are positioned in such a way that massecuite travels through gaps between successive discs, thanks to the rotary movement of the agitator. In B.M.A. crystallisers the heat exchange surface to volume ratio can be either 1.0 to 2.0 m$^2$/m$^3$.

According to Hugot vertical crystallisers may be grouped in series and are often installed in threes so that massecuite is cooled progressively. He further suggests the reheating may be carried out in the fourth crystalliser. It would be necessary to pump massecuites from each crystalliser upto reheating stage.

7.3. In Australia at Victoria Mill vertical crystalliser of B.M.A. design is used for partial cooling of 'C massecuites by 10°C and the partially cooled massecuite is conveyed to horizontal crystalliser for further cooling.

7.4. In the design of continuous vertical crystalliser following points need to be checked—

(i) Massecuite flow and water circulation are in opposite direction to each other. Perfect plug flow of both massecuite as also water has to be ensured so as to obtain uniform cooling without leaving any pockets of massecuite without proper heat exchange.

(ii) Stirrers should be designed properly so as to scrape off thoroughly the stationary cooling elements as any accumulation of massecuite on the cooling surface will result in retarding heat transfer from massecuite.

(iii) The cycle of operation should include period of cooling at the rate of about 1.5° - 2.2°C per hour as also maturity period 2-3 hours each time before and after cooling.

(iv) Pumping of cold 'C massecuites has to be avoided.

(v) Reheating of cooled massecuites without agitation, upto saturation temperature is essential. At no stage should dilution of massecuites be practised.

(vi) Cooling elements have to be leak-proof and the water to be used should be clean soft
and free from suspended matter which would get deposited on the inner surface of the heat exchange tubes or discs.

7.5. Advantages—

(i) Vertical crystallisers occupy much less space and are suited to plants undergoing capacity expansion. They can be installed outside the factory buildings.

(ii) Power required is much low (30-50%) as compared to conventional crystallisers with water-cooling elements.

(iii) Cost of installations is low.

8. CONDITIONING OF COOLED-MASSECUITES

8.1. Massecuites on cooling become viscous and difficult to handle in centrifugals. In order to efficiently bring about separation of mother-liquor from crystals it is imperative to reduce the viscosity of cooled massecuite prior to centrifuging for which two methods are in practice viz., dilution and reheating. In A & B massecuites dilution is brought about by A heavy and B heavy respectively without use of water since the mother liquor from the same massecuite when added to the cooled molasses can very well improve the fluidity of massecuite and improve its centrifuging characteristics by bringing down viscosity. In the case of final or 'C' massecuites, addition of final molasses, which itself is highly viscous serves no purpose and water addition for diluting massecuite has to be resorted to. But dilution of final massecuite is invariably found to result in redissolution of some sugar. Moreover uniform dilution of mother liquor surrounding the crystals is impracticable considering the highly viscous nature of massecuite. Thus even if attempt is made to achieve dilution of cooled massecuite by use of water or dilute final molasses, maintaining the massecuite in supersaturated state, the risk of dissolution of sugar crystals and losing more sugar in final molasses cannot be avoided. Hence dilution of 'C' massecuites for reducing viscosity is not recommended and is now replaced by reheating in modern practice.

8.2. Reheating—Reheating of 'C' massecuite reduces the viscosity and every 5°C rise in temperature is accompanied by bringing down the viscosity by half. In practice reheating of massecuite is carried out in such a way that mother-liquor never reaches the zone of undersaturation and uniform heating is achieved throughout the mass. Application of heat to massecuite to raise its temperature to the saturation temperature has now become universal practice and different systems of reheating cold massecuites have been established as described below.

8.3. Reheating in crystalliser—Massecuites can be reheated in crystallisers, whether in batch operation or continuous system comprising a series of crystallisers, by passing warm water at 55° to 60°C through the heat exchangers. The temperature difference between circulating water and saturation temperature of massecuite should not exceed 2°C. With revolving coils or discs through which warm water is circulating in crystalliser, when the speed is high the reheating will also be quicker due to higher heat transfer rate and if the reheating is quick the chances of redissolution of sugar are minimised. In India Gundu
Rao and Shastry reported rise in molasses purity of 2.0 units by heating cooled 'C massecuite in the crystalliser with Fletcher Blachard cooling elements. In order to eliminate the risk of redissolution of sugar in crystallisers with rotating elements, during reheating rapid reheating of cooled massecuite without stirring was developed in the last two or three decades. Some of these devices are described below—

8.4. Electrical heating—Resistance heating of cooled 'C' massecuites by applying A.C. at 220 V was first tried on small scale by K.S.G. Doss in 1955. In a rectangular box of truncated pyramidal bottom, grid of electrodes is fitted and massecuite allowed to flow continuously over the electrodes. Application of A.C. field results in quick rise in temperature of massecuite. This system was commercially applied in some factories with good results. In Queensland Wright developed resistance heater to be interposed between the continuous centrifugal and crystalliser and reported a gain of 0.1 - 0.15 unit of molasses purity drop. The Queensland reheater consists of two concentric pipes forming two electrodes and the massecuite passing by gravity through the annular space between the pipes. On applying potential difference the massecuite gets heated on way to centrifugal machine. The flow rate of massecuite has to be adjusted to obtain uniform rise in temperature at a definite flow of current. Power required is around 11-13 units per tonne of 'C massecuite.

8.5. Green Smith reheater—A stationary massecuite reheater known as Green Smith reheater was developed by Tate and Lyle in sixties and has been widely adopted in beet and cane-sugar industries. It is a rectangular tank of M.S. construction, in which are placed banks of finned tube elements, through which warm water is circulated. A very high ratio of heating surface to massecuite volume is maintained, which is conducive to minimum residence time of massecuite in the reheater as also rapid rise in temperature of massecuite. Massecuite flows by gravity while warm water circulates counter-current to the massecuite flow. Banks of elements are so arranged as to offer minimum resistance to flow of massecuites. The temperature difference between the outgoing heated massecuite and warm water is only 2° - 3°C which favours reheating massecuite without chances of local overheating and redissolution of sugar.

8.5.2. In Australia finned tubes are employed as heating elements and cooled 'C massecuites are reheated in containers with stationary elements before they are charged to centrifugals. Massecuite flows through a bank of heating elements and is reheated to saturation temperature, while hot water flows through the tubular elements.

8.5.3. In South Africa also the massecuite reheater is a tank fitted with staggered rows of finned tubes through which upward flow of cooled massecuite is arranged.

8.5.4. Transient heater—Designed by Dr. K.S.G. Doss in India, this is a reheater involving no stirring of massecuite. In its earlier version rectangular vertical ducts were housed in a tank but later on, these were replaced by steel coils. In the present design rows of steel coils are placed in a rectangular vessel and cooled massecuite flows over the coils. A valve at the bottom of tank regulates the flow of massecuite as also the temperature of massecuite. Condensate at 60°C is pumped through the coil and no purity rise of final
molasses on account of redissolution of sugar has been observed. These heaters have been installed at a number of factories in India for heating C massecuites from 40°C to 52°C.\textsuperscript{17}

9. WATER REQUIREMENT FOR COOLING

In a water cooled crystalliser massecuite cooling takes place by transfer of heat to the cold water flowing through the elements and also to a small extent through the walls of the crystalliser shell as well as due to exposure of surface of massecuite to atmosphere. The cooling promotes deposition of sucrose from mother liquor on the sugar crystals thereby releasing heat of crystallisation to be absorbed by the cooling water. According to Hugot this heat of crystallisation released is around 8-10% the sensible heat being removed during cooling and should be neglected along with the benefit of atmospheric cooling of massecuite for calculation of water requirement in cooling operation.\textsuperscript{18} The quantity of water required for cooling massecuite can be calculated by following formula—

\[
W = \frac{MC(T_1 - T_2)}{t_2 - t_1}
\]

\(W\) = Kg water per hour
\(M\) = Quantity of massecuite in Kg.
\(C\) = Specific heat of massecuite 0.44
\(T_1\) = Temperature of Massecuite entering crystalliser.
\(T_2\) = Temperature of Massecuite leaving crystalliser.
\(t_1\) = —do— of water entering crystalliser.
\(t_2\) = —do— of water leaving crystalliser.

For Werkspoor continuous crystalliser factor \(a\) is introduced taking into account the cooling of molasses from centrifugals added to crystalliser and the equation is—

\[
W = \alpha \frac{MC (T_1 - T_2)}{t_2 - t_1}
\]

For continuous cooling crystallisers the value of \(a\) is 1.15 - 1.2\textsuperscript{19} and the water requirement is 0.75 - 0.80 kg/kg of massecuite.

In the intermittent system of cooling, in crystallisers with water cooling coils the consumption of cooling water is nearly two and half time the water required in continuous cooling crystallisers\textsuperscript{20} for two reasons—

(i) In intermittent cooling, initially when massecuite is hot the temperature difference between massecuite and cooling water is high and the water temperature leaving crystalliser is pretty high-nearly 50°C whereas at the end when massecuite is cooled the difference between water leaving, arid the massecuite is low 2° - 3°C.
10. CONTROL OF CRYSTALLISER STATION

In the crystallisers the massecuite loses its sensible heat either to the atmosphere or due to the transfer of heat to water and with progressive drop in temperature crystals grow in the massecuite due to desugarisation of mother liquor. The control of operations at this station is thus related to

(a) temperature changes,

(b) saturation temperature,

(c) mother liquor purity.

(A) Thermometers should be installed for observing temperatures of massecuites in all crystallisers and the temperature recorded at regular intervals. In crystallisers with water cooling arrangement the temperatures of both cooling water and massecuites have to be noted. Similarly during reheating of massecuites special attention is to be paid to the difference in temperatures of heating medium and massecuite. Needless to state records have to be maintained about the progress of each and every strike charged into crystalliser from the time of receiving the massecuite from pan upto the centrifuging.

(B) Saturation temperature—While reheating a cooled massecuite care has to be taken not to cross the saturation limit or the saturation temperature which is determined by use of special instruments. One such instrument developed in Hawaii, known as Saturoscope is based on microscopic observation of changes in shape of sugar crystal at the commencement of resolution when the sample of massecuite is carefully heated on the heating stage of microscope. On the stage of microscope are placed electrically heated air-cell with glass cover, heating elements, thermometer and rheostat for determining the effect of raising temperature on the sugar crystal. A small amount of massecuite is placed between two cover glasses on the stage of the instrument. Microscope is focused on the sharp edges of sugar crystal and by gradual increase of voltage the temperature in the saturoscope is raised until the dissolution of crystal is initiated as indicated by the erosion of sharp edge of the crystal. It is necessary to focus the microscope on sharp edge of a crystal. The temperature at which the dissolution commences is the saturation temperature. This method is tedious and in Australia recently P.G. Weight developed photometric method of saturation temperature.

The Australian method is based on the change in the light transparency of seeded syrup in slide mounted on the heating stage of microscope. The light transmitted, during gradual rise of temperature of the liquor, detected by selenium cell initially falls before the saturation but increases rapidly once the saturation temperature is exceeded. Thus the saturation temperature corresponds to the minimum on the temperature light transmission graph. The apparatus consists of a microscope hot stage, on which is placed a sample of molasses with sugar. Light transmitted through the slide is directed to Selenium photovoltaic cell. In the later modification of the instrument, light source was changed to high intensity light emitting diode and selenium cell was replaced by phototransistor device.
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1. FUNCTION

The various grades of massecuites after completion of the sugar crystallisation process contain sugar crystals together with the mother liquor and the next logical step is to separate the crystalline sugar, from the molasses which is a thick liquid. This separation known as purging or 'curing' is effected in centrifugal machines. In the process of white sugar manufacture from cane the sugar separated from first or 'A' massecuite is steam or air dried and conveyed to packing house while the sugars from the remaining massecuites are put back in process either in the form of seed magma or as melt. The final molasses i.e. the mother liquor from final massecuite is sent out of the process house after weighing for storage away from the plant while the molasses from the other massecuites are pumped to pan floor for reboiling in vacuum pans. Efficient purging of massecuite or centrifugal separation of sugar from molasses has a great bearing on—

(a) the quantum of massecuite boiled,
(b) recirculation of sugars and non-sugars,
(c) quality of white sugar and final molasses purity.

Two types of centrifugal machines are employed in sugar industry viz. batch machines and continuous centrifugals. In the past two decades considerable advance has been witnessed in the designs of centrifugals in respect of automatic operation, higher efficiencies and capacities and control-systems which have contributed to improvements in process efficiencies.

2. CENTRIFUGAL STATION

The centrifugal station is invariably located on ground-floor, the operating platform of centrifugal machines being about 1.75 m. above the ground. Below the operating platform are installed mixers or conveyers. The machines are grouped according to the function they are designed for; and are separated for each type of massecuite like A, B, C. The entire centrifugal station comprises besides the centrifugal machines—

(i) pugmills for receiving massecuite from crystalliser or magma from mixers,
(ii) magma mixers wherein the sugar from purging massecuite is dropped.
(iii) conveyers for sugar
(iv) molasses receiving tanks,
(v) control panels, air-compressor, water-heater.
(vi) pumps for magma and molasses with necessary piping as major units.
3. BATCH CENTRIFUGALS

A centrifugal machine essentially consists of—
(a) revolving basket with drive arrangement,
(b) monitor casing.

In a batch centrifugal machine the basket is a cylindrical drum with perforations, supported on a heavy vertical shaft with drive arrangement at the top. Normally the basket is open at the top as well as at the bottom and whereas bottom is closed by a cone at the time of taking the massecuite charge or during running, the top is kept open while charging, the exception being the conical self-discharging machines with no bottom cover. The perforated basket is lined with wiregauze and a perforated brass liner for allowing the separated molasses to flow out, while retaining the sugar crystals.

The basket is surrounded by a fixed casing known as monitor casing which is open at the top and is provided with sliding covers for closing the machine while running. The opening of the casing is the same as that of the basket top and the covers are so shaped as to allow the shaft to rotate freely. In the baskets of centrifugals particularly for curing of high grade massecuites, are suspended water and steam pipes fitted with nozzles, vertically through the top of casing for washing the sugar. A mechanical sugar discharging plough is mounted on the top of casing.

4. CENTRIFUGAL FORCE AND GRAVITY

4.1. Centrifugal Forces—In a centrifugal machine revolving at high speed the centrifugal force exerted on the mass consisting of sugar crystals surrounded by viscous liquor brings about the separation of mother liquor from the sugar crystals. The mother liquor passes through the perforations of screen and the basket while the sugar crystals are retained on the wall of the basket lining. The centrifugal force varies directly as the square of the peripheral speed and mass but is inversely proportional to the radius. This is expressed as—

\[ F = \frac{MV^2}{r} \]

Where: F is the Centrifugal force
r: radius of gyration in m.
M i.e. mass is \( \frac{w}{g} \) or \( W = Mg \)
g being force of gravity = 9.8 m/s/s and
W = Weight in Kg.

\[ \therefore \text{For one Kg. weight of material} \quad M = \frac{1}{9.81} = 0.102 \]
Whenever calculations are based on mass, one Kg mass is the mass of body weighing one Kilogram.

Now \( V = \frac{2\pi \times n}{60} = 0.105 \times n \).

Where \( n \) = revolutions per minute of the machine and 
\( v \) = tangential velocity in m./sec.

the angular velocity \( \omega = \frac{2\pi n}{60} \)

Thus : \( F = (mw^2r) \) in terms of angular velocity.

4.2. Effect of speed and diameter—If we consider a centrifugal with basket diameter of 1015 mm. running at two different speeds 1000 rpm. and 1500 rpm. the force developed will be 2.25 times with the latter speed (1500 rpm.) over that when running at 1000 rpm and the same machine when rotating at 1250 rpm. will develop gravity force 1.56 times more. As regards the influence of diameter of the basket compared to a machine with basket diameter of 1015 m. in the machines of—

(a) 1065 mm. dia. and 
(b) 1220 m. dia.

The centrifugal force will be 1.05 times and 1.2 times respectively the speed remaining; the same at 1000 r.p.m.

4.3. With batch centrifugals the thickness of layer of the massecuite in the basket varies from 100-150 mm. and the centrifugal force acting on the sugar in contact with screen will be much greater than on the sugar in the exposed surface of the mass near the shaft. The mean centrifugal force exerted on the entire mass in the machine will have to be based on mean equivalent radius which is given by the equation.

\[ R_3 = \frac{2}{3} \frac{R_1^3 - R_2^3}{R_1^2 - R_2^2} \]

Where \( R_1 \) is the radius at the screen, \( R_2 \), at the inner wall of sugar and \( R_3 \) is the mean radius while thickness of sugar wall is represented by \( R_1 - R_2 \).

The centrifugal force of machines is expressed in relation to the force of gravity which is equivalent to weight.

\( W = Mg \). Since centrifugal force \( f = Mw^2R \), the ratio of centrifugal force to gravity becomes

\[ G = \frac{F}{P} = \frac{Mw^2R_3}{Mg} \]

Where \( R, R_2 \) & \( R_3 \) are expressed in meters and \( w \) is angular velocity.
5. CONSTRUCTION

5.1. Basket

5.1.1. The baskets are made of special steel and are of sufficient thickness, to withstand the centrifugal force for which they are designed. Perforations are drilled for providing drainage of molasses and the more the openings the drainage area will be more but the strength of the basket will be diminished. Hence a proper balance with respect to perforations is struck without sacrificing the strength of the basket which is subjected to high centrifugal force. Hoops are fitted on the outer periphery of the basket facing the curb section for reinforcement to impart additional strength as an extra safety factor. The baskets are dynamically balanced to ensure true running and the welded sections are examined by X-ray once in few years during off-season particularly after they have been in service for some years.

5.1.2. The perforated basket is lined with two types of screens—

(i) the screen in contact with smooth basket is a brass wire mesh netting with openings of 5-9 mm. interposed between the basket wall and the smooth brass liner which retains the sugar. Another type of backing screen is 'stabbed' liner made of punched special steel or brass sheet,

(ii) A perforated brass sheet covering the backing screen of 0.69 mm. diameter opening and 62 holes per square cm. of area OR about 100 openings per cm² area each of 0.51 mm. dia OR tapered slot openings of 4.0 mm. length and 0.3 mm. width on the inside and 0.7 mm. on the outside. The liner thickness is 0.8 mm. The last one is quite common in Indian plants.

Tromp suggests backing liners of 4 mash iron gauze in contact with the basket followed by 7 mash brass gauze over which is fitted the brass liner.¹ Thus the two wire gauzes should facilitate flow of mother liquor to the curb. The liners should be fitted so as to overlap in the direction of basket rotation. The liners before fitting must have length somewhat larger than the internal circumference of the basket to avoid any gap uncovered and the size should be cut so as to keep minimum overlap since the double layers would offer greater resistance to molasses flow. This overlap is usually 25-35 mm. while after fittings the total overlap is around 60.00 mm.

Any damage to screens either due to some foreign matter striking it or on account of wear must result in sugar passing into molasses, which can be noticed by careful watch on the sugar grains in the samples of molasses emerging from machine. But during the season the damage to screens results in loss of capacity at the centrifugals and replacement of damaged screen has to be carried out by skilled mechanic with minimum loss of time.

5.1.3. The basket is open partially at the top and bottom, being partly covered by circumferential lip of about 15 cm. width subject of course to capacity and different design features. The lip can be either in horizontal plane or slightly sloping and it prevents charged massecuite from leaving the basket during motion. The volumetric capacity of the basket is defined by the space between the screen and the circumference of the inner edge of the lip, which is about 14-15% diameter of basket.
The basket has a spider opening at the bottom to allow discharge of sugar. During charging and running in most designs the central bottom opening is covered by a cone.

Spindle—The basket is supported at the bottom by a spindle which has its top head connected to the system of drive through a suitable coupling. The spindle is made of high grade steel and in some designs its surface is chromium plated to impart corrosion resisting property. The suspension head of the spindle has to be of robust design and each manufacturer has incorporated special features in this design. The application of driving power and system of controlling gyration and vibrations are major considerations in the design apart from safety of the basket. The spindle is suspended in ball and roller bearings.

Drive—Upto fifties belt driven centrifugals were quite common in Indian industry but later they were rapidly replaced by high gravity and high speed machines directly driven by vertical electric motors, which through the coupling transmit the rotary drive of shaft of electric motor to the centrifugal spindle.

Fluid drive machines incorporate the principle of transmission of power through fluid coupling while employing single speed motor. The coupling consists of wheel mounted on motor shaft, which through medium of oil, drives the turbine wheel fitted to centrifugal spindle. Changes in speed of machine for different operations like charging, curing etc. are dependent on the control of oil supply to fluid coupling. High speed machines with fluid drive have been installed in many modern plants in India, particularly for high grade massecuite curing.

Common type of electric drive is provided by four-speed pole changing A.C. electric motor. One of the important features of this motor is the regenerative breaking which gives partial recovery of energy by feeding the braking energy into the mains.

Yet another type of electric drive is the Ward-Leonard system in which the motor runs on D.C. This D.C. drive is favoured on account of ease of speed control and minimum power consumption. Factory A.C. supply is changed to D.C. by converters for this purpose.

The speeds of different operations of cycle are

<table>
<thead>
<tr>
<th>Operation</th>
<th>Speed (rpm)</th>
</tr>
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<tbody>
<tr>
<td>Charging</td>
<td>200</td>
</tr>
<tr>
<td>Intermediate curing</td>
<td>750</td>
</tr>
<tr>
<td>Plowing</td>
<td>50</td>
</tr>
</tbody>
</table>

for flat bottom centrifugals employed mostly in purging 'A' massecuites. With a multiple pole changing motor the above speed cannot be altered with the present frequency of 50 cycles. The motors are designed for maximum charges such as 25 for 'A', 20 for 'B' and 6 for 'C' massecuite curing. In practice complete cycle of different massecuite requires in modern batch machines.

3 to 4 minutes for A curing
3-4 minutes for B curing
12 to 15 minutes for C curing.
The time of acceleration for high speed machines employed for purging high grade massecuites has to be minimum since the time cycles in their case is short, but for final massecuites it is advantageous to have comparatively slower rate of acceleration to prevent packing of crystals which is unfavourable for passage of molasses through interstitial space of the crystals.

6. OPERATION

6.1. The entire operation of centrifugal separation in purging of massecuite involves following steps—

(i) Taking charge—After start of machine, the valve of the pugmill which stores massecuite or magma for centrifugals, is opened and the massecuite charged when the machine is running at low speed of 200-300 rpm. The pugmill valve is closed after the basket is filled to the desired extent. During charging the massecuite climbs up the screen wall of the basket due to centrifugal force.

(ii) Running at intermediate speed—The machine speed is raised to about 700-750 rpm. and it is run at this speed for short period before it is accelerated to the highest speed to prevent packing of sugar in basket.

(iii) Running at full speed—After short duration at intermediate speed the centrifugal running is accelerated to its maximum speed. In the case of machines for 'A' massecuite curing the modern machines are run at 1450-1500 rpm. with the use of electric motors of 50 cycles current. Maximum separation of molasses from sugar is ensured and the machine speed is brought down to 50 rpm. at the end of spinning.

(iv) Ploughing—At about 50 rpm. the sugar is scraped off, an operation termed as ploughing when the bottom cover of centrifugal basked is lifted and sugar discharged into either conveyor or mixer.

(v) After the ploughing stage one complete cycle of operation is over and machine ready for restarting.

In all modern installations of batch centrifugals the above operations are controlled either automatically or in some cases partially automated. The timing of each phase as also the sequence of operation is set on a timer and controlled according to time-setting.

6.2. Water wash and steaming

6.2.1. Water wash is given in the machines in A, B and second purging of final massecuites, while steam is applied only in 'A' purging. The hot water wash is usually started when the machine reaches full speed but some-times it is given in two stages: for a few seconds at intermediate speed to assist the heavy molasses run off before the machine attains maximum speed and thereafter the remaining wash after high speed is reached. The steam wash follows the water-wash at high speed in 'A' massecuite purging.

6.2.2. Water wash is applied after nearly three-fourth of the molasses has been separated and in high speed machines it is started after nearly half the period of running at high speed is
over. Depending on the type of massecuite the period of water application is 5 to 15 sec. According to Benz the relation between the quantity of wash water and the rise in purity of sugar is expressed as under.\(^2\)

\[
P_1 = \text{Purity of washed sugar} \\
P_0 = \text{Purity of un-washed sugar} \\
W = \text{Quantity of water} \% \text{ massecuite.}
\]

6.2.3. Super-heated wash water—Condensate water under pressure of 3.5 Kg/Cm\(^2\) pressure and heated to 115\(^\circ\) - 125\(^\circ\)C is being increasingly used in place of steam in the high speed centrifugals. Superheated wash-water however does not remove the moisture of sugar to the same extent as the steam but for commercial crystal sugar, the remaining moisture can be removed on the hopper by hot air.

The spray nozzles have to be designed in such a manner that the distribution of water is uniform over the entire height of sugar layer. Wash water consumption is about 5\% on sugar.

6.3. The molasses separated in the initial phase which more or less corresponds to the purity of mother liquor of the massecuite is separately led to a tank and sent to pan-floor as 'heavy' molasses, like 'A' heavy 'B' heavy.

The molasses collected from casing after application of water wash is usually of about the same purity as the massecuite from which it is obtained and is termed as light molasses which also is pumped to pan floor.

6.4. Double purging—Some massecuites have to be purged twice for obtaining high purity sugar at each stage. This is particularly essential for curing of low-grade massecuites. In double purging, the massecuite, is cured without use of wash water or with very little application of wash and the sugar is made into magma in mixer by continuous addition of light molasses of the same massecuite or water. This magma is pumped into pugmill or distributor above the battery of afterworkers and repurged. The advantages of double purging are

(a) foolproof separation of heavy and light molasses,

(b) high purity of sugar assured.

The disadvantages of the system lie in.

(a) the increase in number of centrifugal machines. "

(b) crystal damage to some extent in pumping of magma to afterworker battery and

(c) requirement of additional equipment like mixer, pump, piping etc

In some plants all the massecuites are double cured but the most common practice is to double purge all 'C or final massecuites.
Keeping in view the requirements of production of big grain white sugar and advantages of employing minimum equipment for operation the following system of curing is recommended.

(i) Single purging of 'A' massecuites in high gravity machines with thorough separation of 'A' light and 'A' heavy molasses.

(ii) Single purging of 'B' massecuites and one intermediate massecuite in continuous centrifugals with provision for double curing 'B' when the sugar is to be used as seed for 'A' boiling.

Alternatively: Double purging of 'B' massecuite in high gravity batch machines.

(iii) Double purging of 'C' of final massecuits in continuous centrifugals.

6.5. The system of operation for purging different types of massecuites prevalent in India can be described as under—

1. 'A' Curing—In 'A' massecuite purging since the sugar separated is sent for packing as final product of manufacture, extra care is exercised in removing the last traces of molasses adhering to crystals and also partially drying the sugar in the machines. To achieve this objective removal of bulk of molasses is followed by application of hot-water wash for 15-25 seconds. Usually condensate of 70°-80°C is sprayed through nozzles for this purpose and this water wash is immediately followed by application of steam at 5-5.5 Kg/cm² or superheated wash water of 120°-130°C.

2. 'B' or intermediate massecuite curing—In this case the molasses separation is important and the sugar has to be of high purity, which is accomplished by employing hot water wash. As the sugar is put back in process either as seed or melt, no steaming is required, but the sugar must be free from molasses.

3. 'C' or final massecuite curing—In 'C' curing the aim is to separate maximum amount of molasses with minimum loss of sugar resulting from redissolution of sugar on account of water wash. Thus the water wash is either completely avoided or if required the water to be applied has to be absolutely minimum. Any sugar going along with this final molasses is lost forever as far as the manufacture of sugar is concerned since this molasses is thrown out of the process.

In respect of use of water wash for A and intermediate curing following points need to be kept in mind:

(i) The surplus molasses in the massecuite which imparts fluid characteristic to the massecuite is readily removed while the molasses which fills the voids in the mass of crystals is difficult to separate. The molasses adhering to crystal is still more difficult to remove and the purpose of water washing is to separate the molasses occupying the space between crystals as well as the film surrounding the sugar crystals.

(ii) Application of water is invariably accompanied by dissolution of sugar, and enriching the sugar content of mother liquor. This necessitates use of just the required amount of water which will give the desired quality of sugar.
6.6. Cycle of operation—A centrifugal machine cycle involves—

(0) Charging,

(it) acceleration

(II) running at full speed

(iv) discharging.

For 'A' massecuite purging the time required at each phase of operation is usually as follows—

(i) Charging 30-40 Sec.

(it) Running at intermediate and full speed 90 Sec.

(iii) Braking 15 Sec.

(iv) discharging 30-40 Sec.

Total Time 3 min. - 3 min 10 Sec.

Water wash of 5-10 seconds is many times applied soon after charging before the machine reaches full speed, which facilitates heavy molasses separation. The second wash of 10-20 sec. is given soon after the full speed is reached followed by steaming for 15-20 sec. The total cycles of one machine in one hour are about 15-20 for both 'A' and 'B' curing. For 'B' and intermediate massecuite purging the time cycle is almost the same as for 'A' except that no steam application is required.

For 'C' or final massecuite purging the time required at each phase of operation is approximately as under—

1. Charging 60-90 sec.

2. Intermediate speed 60-90 sec.

3. Highspeed 5-6 min.

4. Deceleration 40-60 sec.

5. Discharge 2-3 min.

Total Time 10-12 min.

Thus for final massecuite curing a machine will complete about 5-6 cycles per hour.

7. FACTORS AFFECTING CENTRIFUGAL PERFORMANCE

7.1. Work at the earlier crystallisation stages, particularly at the pan station has a great bearing on the centrifugal performance. An important consideration in this behalf is the quality of massecuite to be purged in respect of—

(a) Uniformity of grain size and

(b) viscosity of mother liquor.
(a) Grain size—Uneven grains have a packing effect on the layer of sugar which renders the passage of molasses difficult. False grain or conglomerate formation in pans or even in crystallisers leads to uneven size of sugar grains and since the molasses has to travel through the voids in the crystals to the screen of the basket, mixed grains reduce the effective area of passage thereby affecting adversely the separation of mother liquor. Many times in high speed centrifugals a layer of molasses is formed on the sugar wall which gives clear indication of uneven grain size of sugar crystals. In extreme case when fine grain proportion is high the screen holes can get blocked.

In ‘C’ massecuite spinning the problem of mixed uneven sized sugar can assume serious proportion in view of the viscous nature of molasses to be separated. One of the ways to partially improve curing in such case is to increase the period of acceleration to high speed and run the machine for longer periods at intermediate speed. Low gravity centrifugals of older design can handle such bad massecuites much better than the modern batch high speed machines in view of less dense packing of sugar mass in the former. For high grade massecuites with nonuniform grains double purging improves matter, though the overall results are affected. In any case the inadequacies and shortcomings in boiling and crystallisation in respect of grain size of massecuite cannot be effectively rectified at centrifugal station and the net result of lack of uniformity, of grain size is poor quality of sugar coupled with higher recirculation. Moreover it leads to higher sugar loss in the case of final massecuite purging.

(b) Viscosity—In curing low grade massecuites viscosity plays a crucial role in separation effect at the centrifugals. Higher viscosity of massecuite and mother liquor brings down the rate of separation and passage of molasses through the voids of crystals to the screen. This situation can be improved by heating and dilution of massecuite to bring down the viscosity. But heating is preferred as 5°C rise in massecuite temperature can bring down the viscosity by 40-50% and it is advisable to reheat the low grade massecuite to saturation temperature i.e. 52°C-54°C before curing and dilution is to be avoided as far as possible. The main reason for longer duration of purging required for final massecuites as compared to ‘A’ massecuites is the viscous nature of mother liquor to be separated. When processing over mature cane or stale cane usually difficulties in ‘C’ curing are experienced on account of very high viscosities. The vertical continuous centrifugals offer a good solution to the problem of handling viscous low grade massecuites.

7.2. Precautions in operation—With favourable characteristics of massecuite in regard to its purging quality the performance of the centrifugals will be governed by special care exercised in respect of the operational features. Some points, which deserve special mention are as under—

(i) Cycle of batch machine—The time fixed for each phase of the machine operation needs to be checked off and on and changes made in the settings of the timer to

(a) obtain maximum capacity,

(b) use minimum wash water and

(c) produce good quality sugar.
(ii) Screen—Screen damage is indicated by crystals passing into molasses which needs to be checked often. In particular for final massecuite purging the screen has to be in good condition as damage to screen results in irrecoverable loss of sugar. Sometimes screens get damaged due to external objects like pieces of metal finding way to basket.

Screens have to be cleaned after a couple of hours' operation for clearing the screen openings blocked by crystals by use of water or steam.

(iii) Covers—The air rushing in running batch machines has a cooling effect which dries the molasses in the upper layers of mass with adverse effect on the separation of molasses. In Java air saturated with water at the same temperature of massecuite was blown into the running basket which improved the quality of 'C' sugar even in low speed machines. In all the centrifugals the covers should be kept closed during running to prevent the cooling and drying effect of outside air.

(iv) Sequencing—To avoid power kicks arising out of simultaneous starting of high speed centrifugals, which are high power consuming units it is essential to start the machines of a battery in a definite sequence so as to maintain steady power load of the centrifugal station.

8. SELF DISCHARGING MACHINES

The baskets of these machines are of steep cone type without any bottom closing cone. The bottoms of these baskets are conical in shape with circumferential wall and the sugar is dropped without any mechanical plough as it falls by gravity from the walls of the basket at the end of spinning cycle when the machine comes to a halt. The slope of bottom for A and B machines is 45°-50°. For distribution of massecuite at the time of taking charge a disc is mounted on the shaft inside the basket. The disc serves to evenly distribute the charge by centrifugal force, on the screen. These machines are mostly used for 'A' or 'B' massecuite purging. The main disadvantage with this type is the high moment of inertia and torque and consequently increased power requirement. Moreover the sugar cannot be dried properly as it has to drop of its own accord.

9. AUTOMATION OF CENTRIFUGAL OPERATION

9.1. Modern high speed centrifugals operating as batch machines involve following steps in one complete cycle of operation.

(i) starting and taking charge,

(ii) operating at intermediate speed of 750 rpm.

(Hi) acceleration to high speed and running at high speed,

(iv) water-wash and steam wash

(v) separation of heavy and light fractions of molasses,
(vi) lowering the speed to 50 rpm. for discharge of sugar.

In present day practice automation has been introduced for these stages, in two ways. One complete automation with recycling arrangement and another is partial automation.

In semiautomatic machines—

(i) starting cycle,
(ii) charging and
(iii) ploughing the sugar for discharge are manually controlled by the operator, the remaining phases being controlled automatically in accordance with the time setting fixed on the timer.

9.2. In complete automatic machines different devices are adopted for charging the required quantity of massecuite. In one type the massecuite gate of the massecuite pugmill is air-operated and charge feeler mounted on the curb top measures charge and closes the discharge gate of the pugmill. A servo motor mechanism is connected to gate and controls the air-flow to the gate air cylinder. Thus the position of feeler shoe regulates the opening and closing of gate.

In another design measuring electrode probe provides impulse for electropneumatic operation of gate valve of the pugmill. During charging as soon as the electrode touches the massecuite in the basket the gate valve is closed.

9.3. Automatic discharger—As soon as the spinning at high speed is over, the deceleration starts and the machine reaches the ploughing speed of 50 rpm. when the cone closing the bottom of basket is raised by air operated fork. The plough can be either hydraulically or pneumatically or electrically operated depending on the design. In some centrifugals the ploughs remain locked inside the basket when not in use and the fourway movements of the discharger shoe viz. downward and upward also 'in' and 'out' during sugar discharge operation are controlled by air cylinders. In one type of centrifugals reverse direction ploughing is adopted wherein the basket revolves at low speed in the anticlockwise direction. The plough is detached from the safety ledge and enters sugar wall of the basket and moves downwards. After discharge of sugar it returns to its original position and the bottom cone closes the basket discharge opening after which the machine restarts its next cycle by moving in the clockwise direction. The main advantage with this arrangement of reverse direction ploughing is that the shoe of the discharge is in the direction of the rotation of the machine during spinning preventing the plough to enter the sugar wall at high speed running of the machine. But the disadvantage of this system lies in the serious trouble faced when the sugar is not sufficiently dry, and the sugar-wall collapses over the cone closing the discharge valve, when the motor speed is reduced and then the direction reversed. This problem of sudden dropping of wet sugar can be overcome by extending the drying time of sugar. In centrifugals with ploughing in the same direction as the basket this problem does not arise.

9.4. For mother liquor outflow a gutter is provided behind the centrifugals with partition for separate collection of light and heavy molasses from the curb. In both semiautomatic and continuous centrifugals the syrup separation devices are provided which are usually
pneumatically operated and the run off from the curb are separated into light and heavy fractions. The molasses outlet is through a diverting spout which is moved to direct molasses to the light or heavy molasses gutter automatically.

9.5. In automatic machines, a number of safety devices are provided which include

(i) limit switch for feed valve,
(ii) limit switch for discharge valve,
(iii) limit switches for plough and discharge valves,
(iv) switch to shut down machine when gyration exceeds the preset value
(v) emergency stop.

In the control panel encased in a cabinet are located timers for machines on which the time is adjusted for each phase of machine operation to suit the requirement of each type of massecuite. For a battery of centrifugal machines, in order to avoid simultaneous starting of different machines adequate control is also provided to avoid sudden current draw and maintain steady power consumption.

In automatic centrifugals some centrifugals which have no recycling arrangement have to be restarted after completion of each cycle. Automation of centrifugal operation has led to—

(a) improved performance in respect of uniformity of operation,
(b) labour saving since the entire battery of centrifugals can be managed by few workers, and
(c) maximum utilisation of installed capacity in terms of output.

10. CONTINUOUS CENTRIFUGALS

10.1. The principal disadvantages of batch machines for centrifugals separation are—

(a) low efficiency in the use of energy because of acceleration and braking in each cycle
(b) complex nature of motor which has to have different speeds for different phases of operations,
(c) loss of time in charging and discharging, Constant endeavour on the part of designers and machinery manufacturers has resulted in introduction of continuous centrifugals since 1960 and in the recent past these have replaced the batch machines for low grade massecuite purging. Out of the two major types of continuous centrifugals the pusher type machines with horizontal axis are no longer favoured but the vertical conical machines with vertical axis are in widespread use in the industry. In continuous centrifugal a constant stream of massecuite is charged and sugar flows out continuously. These centrifugals work essentially on thin layer principle and efficient molasses separation is obtained even from messecuites with mixed size grain.
10.2. Pusher type machine—

This machine rotating around horizontal axis consists of cylindrical stepped basket divided into 4-6 sections of increasing diameter. The basket with screens as its sides is open at both opposite ends, and rotates at 600-1000 rpm. Inside the basket the massecuite is fed at the innermost section with smallest diameter by a pipe and gets distributed by centrifugal force. A hydraulically operated piston with to-and-fro movement inside the basket pushes the material from the smallest section to the succeeding larger ones. The sugar comes out continuously at the open end of the machine while the molasses collects in the casing surrounding the basket. Wash water is applied at one of the intermediate stages through nozzle connected to a water-pipe. This type of centrifugal is suitable only for 'B' massecuite curing and the sugar is usually wet. The sugar crystals get damaged as they are pushed from step to step in these machines.

10.3. Conical basket vertical machines—The conical basket of vertical continuous machine is perforated and lined with screens with either 0.06 mm. or 0.09 mm. opening holes. The angle of the conical basket is usually 34° for final massecuite curing and 30° for afterworkers or intermediate massecuite. The drive for machines is provided by a motor mounted behind the machine connected to the pulley at the bottom of the machine with belts. The top of the machine is open while the bottom shaped like cylinder is closed. Some manufacturers prefer to connect motor directly to the machine. The basket rotates at 1500-2000 rpm. Wash water pipe is suspended in the basket with suitable nozzles, along the wall.

Massecuite feed in some designs is arranged at the centre of the bowl or off the centre by the side. On account of centrifugal force the massecuite feed at the bottom rises upwards the screen of the conical basket. As it moves, the separation of molasses and sugar takes place the molasses passing through the perforations of the screen to the curb. Washing of sugar is effected continuously and sugar is discharged over the top rim into surrounding annular compartment. For 'C' massecuite wash water application at the point of entry of feed into the cane is preferred for reducing massecuite viscosity before it moves up the screen surface. In one design steam is applied at the feed point while in some centrifugals steam is admitted into massecuite feed pipe.

10.4. Crystal breakage—One problem associated with operation of continuous centrifugal, which precludes its adoption for white sugar massecuites is the damage to sugar crystals. The breakage of sugar grain is the result of—

(i) erosion of crystals as the mass in centrifugals moves up mainly due to thin layer,

(ii) impact of crystals against the wall of annular casing as they are, thrown out of the basket.

With the existing designs the former i.e. effect due to erosion seems unavoidable and the second cause of damage is sought to be tackled by providing outer casing of very large diameter so as to reduce the speed of impact of crystals against the casing wall. According to Hugot the speed of impact of crystals is around 9-18 m/sec. Retention of
more molasses with sugar would considerably bring down the breakage of crystals but this is undesirable from the process point of view.

10.5. Molasses purity—For low grade massecuite purging the common experience is that the molasses purity is higher with conti-machines by one unit or so compared to that with high speed batch centrifugals under identical conditions. Wash water application is essential for final massecuite curing in continuous centrifugals for obtaining proper separation of molasses as also high purity of sugar (> 80). An additional factor which can contribute to the increase in molasses purity is the use of water in relation to massecuite feed flow. If at any time flow is reduced while the wash-water remains unchanged the sugar crystals will be partially dissolved.

10.6. Screens—The nickel screens used in vertical continuous centrifugal are manufactured by special process of electroforming. The screens have conical perforations in slots of 0.06 mm. or 0.09 mm. width. The nickel screens are hard chromium plated for increasing wear resistance and the slot opening can be as small as 0.04 mm. for 'C' massecuite spinning. The screen opening area is around 7-10% of the total screen area. The perforations of screens are conical in shape, smaller opening being maintained on the sugarside, while it converges inside. Compared to the screens employed in batch machines these screens are thin with about 0.25 mm. thickness. Due to wear in running they are replaced after about 60-90 days running.

10.7. Experience with continuous centrifugals in India.

In Indian industry continuous centrifugals were introduced nearly two decades back and since the last 10-12 years they are widely used for 'C" curing and 'B' massecuite curing. Machines of different modern designs of international manufacturers are installed in sugar mills and these are found to be quite suitable for intermediate and final massecuite spinning. The experience gained with these machines as also the investigational work done with them is briefly summarised as under—

(i) Spinning of 'C' massecuites with continuous centrifugals results in higher molasses purity by about 1.0 unit compared to batch high-speed machines but the sugar purity is uniformly 80 and above. However recent trend in maintaining small size grain of 'C' massecuite of 0.2 to 0.22 mm. as against the previous practice of 0.3 to 0.4 mm. grain size has more than compensated for this and low purities of molasses are obtained by—

   (a) reheating of 'C' massecuites to 50-52°C before curing,

   (b) regulating feed of wash water and preferably using 50-60% final molasses solution in place of water. In a few factories screens with 0.04 mm. hole aperture have been fitted with beneficial effect on molasses purity reduction.

(ii) With continuous machines as 'C' foreoworkers, the afterworkers are necessarily continuous centrifugals. 'B' massecuite curing in continuous machines yields high purity sugar but the crystals are damaged and of varying sizes due to attrition. Whenever 'B' sugar is to be used as seed for 'A' boiling the practice is to double purge 'B' massecuite. In some designs the melting of B or C aftercured sugar is accomplished in the concentric casing for sugar.
10.8. Advantages—Continuous centrifugals hold great promise for future and last two decades have witnessed several special design improvements and innovations which have enhanced their utility. The main advantages are—

(i) Steady and reduced energy consumption on account of continuous operation. The installed power of a machine which handles 2-3 t. 'C massecuite per hour is 40-45 k.w.

It is customary to control flow of massecuite into centrifugal on the basis of ammeter reading of the motor of the machine i.e. load on the drive.

(ii) It is possible to spin 'C massecuites containing sugar grains of 0.18 to 0.2 mm. size and obtain sugar of >80 purity and low purity of final molasses, which is not possible with batch centrifugals. Even massecuites with uneven size of grains can be efficiently purged in continuous machines without affecting the results, mainly due to the thin layer of massecuites in the basket.

(iii) Capital expenditure and maintenance costs are low.

11. MODERN TRENDS

11.1. In recent years, the centrifugal manufacturers have tried to improve the overall performance of the batch centrifugals by introducing—

(i) greater automation, and

(ii) safety devices.

In continuous machines, the efforts are directed towards—

(i) minimising the crystal breakages by incorporating new design features and

(ii) modifications in feed and wash systems. Recent trends in the designs of both batch and continuous machines are as under—

11.2. Batch machines—In batch machines the advances relate more to some design details; greater stress being laid on automation of all phases of operation. Completely automatic recycling machines have been introduced. With the rapid development of electronics, the controls involving solid state timers, which are free from moving parts and have long life, have become common. The sequencing of the centrifugals in a battery has also been made automatic.

In respect of system of electric drive thyristor controlled d.c. drive is gaining acceptance. The speed control of motor is based on thyristor which is a solid state semi-conductor without moving parts and functions as a controlled rectifier.

Several safety devices have been introduced in the modern centrifugals. Motors are protected by thermal overload relays and they cannot be energised to high speed without being operated at low speed for preset time. Similarly the massecuite charging gate cannot be opened when the machine is running at high speed; the plough will not operate unless washing has taken place, basket discharge valve and plough are interlocked, centrifugal is automatically stopped when gyration exceeds certain limits.
11.3. Continuous machines—In continuous machines it is essential that the massecuite fed to basket is evenly distributed for proper utilisation of screen area and avoiding vibrations and recent machines are provided with deeper and larger accelerating cups. In some designs water spray is arranged so as to mix with the massecuite as it falls on the cup. Steam mixing with the feed before it reaches the screen has also been incorporated in some machines, some manufacturers have introduced continuous melting of sugar which is discharged as clear sugar melt from the machine casing. This is accomplished on account of high impact speed of crystals on liquid film, which dissolves the sugar crystals, thus eliminating screw conveyer and melter for the centrifugal sugar.

11.4. Recent work in Australia concerning the power consumption in continuous centrifugal has shown that the power loss due to windage, which depends on the design of the basket and speed represents around 10-40% of total power used, while the power required for separation of molasses is about 50% of the total power consumed. The molasses flow-back can increase the power required for massecuite processing by 50% when the flow of molasses is uneven. This tendency of molasses leaving the screen, to stick to the outside of basket instead of flowing tangentially is termed as 'teapot effect'. This flow back of molasses results in some molasses emerging from the annular chamber and getting mixed in sugar stream, resulting in lowering the pol of sugar and overall performance. Perfect sealing between molasses and sugar compartments is absolutely essential to prevent the molasses and sugar remixing and water testing of machine is suggested to check the sealing between these chambers.

Considerable amount of investigational work has been carried out in Australia on the study of various aspects of the continuous centrifugal design and a hybrid continuous centrifugal was developed at Bundaberg for handling affination magma and low grade massecuite. A conical basket was mounted on a batch centrifugal basket and side feed provided, and satisfactory results have been reported with affination sugar magma. Further progress on the use of hybrid centrifuge for high grade massecuite curing is reported recently, but the problem of crystal breakage remaind unsolved. However the 'Supercentrifuge' developed by university of Queensland and NQEA shows promise for future application both for high grade and low-grade sugar separation. The problem of crystal damage due to high velocity impacts with casing is reported to have been brought under control and power consumption, is also very low. Capacity reported is very high by existing standards viz. 75t. for A, 45 t. for B and 35 t for C massecuites per hour of operation.

12. ACCESSORIES

At the centrifugal station besides the centrifugal machines a number of other machinery units are involved in the operation. The centrifugal station receives the different types of massecuites from the crystallisers and sends out

(i) white sugar for packing,

(II) low grade sugars for melting or as seed to pan floor,
(in) molasses from all massecuites except the last one for reboiling on pan-floor and

(iv) final molasses out of the process house.

For performing all these functions a number of other accessory units are installed some of which are described below—

(a) Pugmills—The massecuite from crystalliser is received in mixers, located above the batteries of machines for different massecuites. These are M.S. troughs with stirrers designed to hold massecuites or magma corresponding to nearly half an hour's requirement of particular battery of centrifugals. The pugmills or mixers for 'A', 'B' or intermediate massecuites are fitted with stirrers consisting of simple shafts with arms for keeping the mass in motion, connected to driving motor through reduction gear. For 'C' massecuites however two types of pugmill systems are installed: one in which coils or disc type hollow elements are fitted to shaft for circulating hot water and second, stationary water heaters installed in troughs for quick reheating of 'C' massecuite before purging. The pugmill proper has simple stirrers and the stationary heater is interposed between the pugmill and centrifugals and this system gives efficient spinning of viscous 'C' massecuites in the continuous machines as the heated massecuite flows directly into the centrifugals.

(b) Mixers—The sugar to be recentrifuged is discharged from machines directly into mixers. This sugar is mixed with a part of same liquor which is obtained from the curing of the same magma as for instance the 'C' sugar from 'C forecured centrifugals is made into magma by mixing it with 'C light molasses. The magma mixer is a trough with stirring arms attached to a shaft which in turn is connected to a motor through reduction gear. On top of the open trough of the mixer is suspended a pipe with perforations for uniform mixing of sugar with liquor. Alternatively water is sometimes used in place of liquor for making magma. The mixer outlet is connected to suction of a magma rota pump which pumps it into the pugmill of afterworkers. The molasses film adhering to the sugar crystals is mixed with the light molasses and in the afterworkers, it gets detached and application of wash water in the machine renders the sugar crystals free from molasses. In the mixers of 'C' afterworkers the magma is made in water and sent to melter.

(c) Molasses collection—Molasses from monitor casing is received in gutters with outlets connected to small receiving cylindrical tanks from which molasses is pumped to pan floor by special pumps.

(d) Control system—A control pannel is housed in a steel cabinet with the necessary timers and switches. A compressor is installed near the centrifugal battery for supply of air at 3-5 kg/cm² pressure for pneumatic operations involved in different phases.

(e) Pumps—Molasses is handled by gear pumps, rotary pumps or screw pumps while magma for mixers is pumped by rota pumps.
13. SUGAR CONVEYERS

13.1. White sugar discharged from centrifugals is conveyed on grass hopper to sugar elevator chute. The grass hopper conveyer is a wide shallow trough usually of G.I. sheet which vibrates by an eccentric drive. The grass-hopper supported on flexible slats is usually of 1 to 1.2 m. width. Flexible strips attached underneath the hopper, are inclined at 60° to the horizontal and are mounted on angles on the ground floor. The rocking movement of the trough throws the sugar forward and connecting rod fixed underneath the hopper imparts the vibrations to the hopper conveyer.

In modern Indian plants in 'A' battery working the white sugar (meant for bagging) from first single tray hopper is discharged into a multitray grass hopper with hot air blowing arrangement. The hot air blows through the space between successive trays over the sugar and reduces the moisture of sugar. Air from air blower flowing through heater is connected to the first step of the grass hopper. The heated and partially dried sugar from this grass hopper is further discharged into second multitray grass hopper provided with cold air blowing arrangement. With hot air-treatment followed by cold air contact, sugar of required temperature and moisture is obtained. The lumps of sugar formed are separated over coarse screen fixed at the end of hopper.

13.2. Sugar elevators—It is essential to transport the dry sugar from hopper to top of sugar grader which is accomplished by a bucket elevator. The elevator may be either straight vertical or inclined. Encased in a closed steel case the elevator consists of two strands of endless chain and the buckets are bolted between two chains, the distance between the buckets being around 30-35 cms. The elevator moves at speed of about 20-30 m/min. and lifts the sugar to a height of 10 to 15 m. and delivers it into the chute leading to top of sugar grader. The chains move over two pulleys at top and bottom while the drive is provided at the top. One or two inspection doors located at the lower end enable examination of chains whenever required. On cleaning day thorough inspection of the entire chain is required when worn out links can be replaced.

14. GRADER

The grading of sugar involving separation of different size grains is performed in the sugarhouse. The elevator delivers the sugar from hopper to the top of grader through a wide chute. A rotating distributor spreads the incoming sugar over the entire width of the top coarse screen. The function of the grader is to classify sugar into different size grains and to separate small lumps as well as dust from the sugar to be marketed. The entire equipment is of sturdy construction consisting of 3 to 4 screens enclosed in a steel frame. The screens bolted in frames have separate chutes at the discharge ends. The grader is a vibrating mechanism with screens inclined at about 35° to the horizontal. The vibrations generated in the screens allow separation of oversize and undersize grains at each screen, the oversize grains flowing over screens are collected at the chute. With three or four screens it is possible to separate three grades of sugar conforming to different size grains. The sugar passing through lowest screen is very fine in nature and is usually discharged into a mixer positioned below the grader for making magma which is
pumped to panfloor for being used as seed for 'A' boiling. For removing fine iron specks from sugar magnetic separators are attached to the chutes from which sugar is sent for marketing.

The sugar received from centrifugals contains good amount of very fine sugar dust which has to be separated at the grader. The dust separation system incorporates an exhaust fan to suck the dust, a separator and dust melting arrangement. Dust catching system not only saves wastage of sugar but also protects the equipment and environment in the sugar house. Moreover the sugar dust is explosive by nature and release of sugar dust in an enclosed surrounding is fraught with grave risk.

Usually in modern plants two to three graders are installed each capable of handling 10-12t. sugar, and receiving part of sugar delivered by the elevator.

15. SUGAR WEIGHING AND PACKING

In India the sugar is filled in 100 kg. hessian jute bags and weighed on scales. In some countries the practice is to use 50 kg. paper bags or polythene woven bags for packing. The weighed bags are stitched at the open end employing electrically operated stitching machine with belt conveyer attachment.
REFERENCES

8. Personal communication.
10. Ibid.
LOW HEAD VACUUM PAN

Fig. 1.
Vacuum Pan with Circulator

Fig. 2.
HORIZONTAL PAN TRANSVERSE SECTION

Fig. 3.
Fig. 5.
BLANCHARD  CRYSTALLIZER

Fig. 7.

STATIONARY HEATER

Fig. 8.
Fig. 10.
VERTICAL CONTINUOUS CRYSTALLISER

Fig. 11.
PAN CRYSTALLISER AND CENTRIFUGAL

Fig. 12.
1. TECHNIQUE OF WHITE SUGAR PRODUCTION

1.1. In the cane sugar industry depending on the type of sugar manufactured three types of factories exist:

(i) Plants producing raw sugar
(ii) those that produce direct consumption white sugar from cane
(iii) mills which manufacture refined sugar from cane.

In raw sugar mills the sugar is produced mostly by employing defecation process of clarification using minimum amount of lime. In the plants which have small refineries attached to cane sugar mills, the washed raw sugar is produced by conventional process of raw sugar manufacture and sent to refinery unit attached to the mill. In the production of mill white sugar, juice clarification is accomplished by either sulphitation or carbonation. In India most of the sugar mills have crushing capacity in the range of 1500 to 3500t cane per day which in effect amounts to 170-375 t sugar production per day. The cane sugar mills of many sugar producing regions like India, Australia etc. operate from 3-6 months in a year in a period which coincides with the dry weather period of a year, but this sugar has to keep well protected from deterioration in subsequent wet weather conditions.

1.2. Quality aspects:

In table 1 is presented the composition of mill white sugar in Indian sugar mills employing double sulphitation process. Compared against the background of the specifications prescribed by Indian standard Institution for white sugar and international standard for refined sugar it is observed that:

(i) The Sucrose percentage of commercial sugar actually obtained is much higher than that prescribed in the standard, but slightly lower than that of refined sugar.

(ii) Mill white sugar contains higher amounts of (a) suspended impurities (b) ash and (c) $S_2O_3$ than the refined sugar.

(iii) The colour value of white cane sugar approaches that of refined sugar but is usually on the higher side than that of the latter.

(iv) In actual practice the quality standards of white sugar far exceed the norms prescribed in standard specifications.

For domestic consumption the buyer is guided by the colour, lustre and grain size of the sugar crystals his preference being obviously for white lustrous sugar of even grain size. For industrial purposes however the major consideration in regard to quality of sugar is
the level of different impurities in dissolved state as well as in suspension apart from the colour value. Moreover to fulfill the consumer demand in some regions the factories have to manufacture big crystals of 0.8-2.0 mm size while simultaneously maintaining high standard of colour. The moisture content in commercial sugar has to be low enough in order that the preservation of sugar from the time of packing till it is marketed is proper even in the case of small grain sugar of 0.6-0.7 mm size.

2. INFLUENCE OF OPERATING CONDITIONS

2.1. The two major areas of plant operation where control is essential for maintaining high standard of quality of sugar are (a) Cane quality (b) process operation.

2.2. Cane Quality—Cane tops contain polyphenols and other colour forming compounds, which if not eliminated at the clarification stage contribute to dark colouration of sugar crystals. It is essential to remove immature tops properly in the interest of avoiding this problem. And while dealing with cane in which phenolic content is high the elimination by usual sulphitation may not be satisfactory which would result in imparting dark brown tinge to sugar crystals. In such cases increasing doses of phosphates and also lime has been found to improve the sugar colour in as much as generally calcium phosphate precipitate removes the colour and colour precursors like phenols more efficiently than either calcium sulphite or calcium carbonate.

Immature cane contains higher amount of reducing sugars and colour precursors and studies in Taiwan have shown higher colour values in the early periods of crushing campaign when immature cane is processed by carbonation method of juice clarification. The colour value was found to be lowered as the cane reached maturity but tended to rise again as the cane became overmature with increase in invert sugar content. Mature cane processing is favourable even for maintaining high standard of sugar quality.

2.3. Process operation:

The method of cane juice clarification has an important role to play in the process of white sugar manufacture. Defecation alone is not able to fulfill the conditions conducive to good quality sugar manufacture as shown by the results of attempts to produce white sugar only by following the defecation despite boiling 'A' massecuite pans on high purity medium including melt from sugar of low grade strikes. The results obtained clearly showed the limitations of eliminating brown colouration of sugar crystals at crystallisation stage. Double carbonation or its different variants have been found to give consistently good quality white sugar though in some places the keeping quality of sugar from this process has created problems. Double sulphitation method as followed in most of the sugar mills in India has been acclaimed as a successful method for good quality white sugar provided precautions are taken in regard to control of operations. In the past decade the new process of treatment of syrup coupled with juice clarification, employing surface active agents developed by Tate & Lyle is reported to have produced good results with regard to quality of direct consumption white sugar.
3. CLARIFICATION

Irrespective of the method of juice clarification followed the most important factors from the point of view of efficient removal of colour or colour forming compounds are

(i) Optimum dosage of lime

(ii) strict pH control

(iii) minimum contact of juice with high temperature as also high pH.

In sulphitation process, apart from optimum lime dose a certain minimum amount of phosphate has to be maintained in the raw juice so that adequate amount of tricalcium phosphate precipitate is formed to facilitate colour absorption. Studies by S.C. Sharma point to the significant part played by phosphate precipitate in removal of colours and melanoidins. In north India when dealing with a certain cane variety the juices were found to contain higher amount of phenolic bodies which created problems in clarification. After increasing the lime dose, preliming and raising the phosphate level in juice could the problem be solved. In sulphitation process it is absolutely essential to vary the lime doses as also $P_2O_5$ level to meet the problems encountered on account of changes in the composition of juice and the optimum conditions of juice treatment such as

(a) Temperature of preheating

(b) Preliming, presulphitation or simultaneous sulphitation

(c) Doses of chemicals.

have to be determined by carrying out experiments.

The main drawback of the conventional sulphitation system as adopted in most of the plants is the threefold or fourfold increase in suspended matter during concentration and high impurities in suspension in syrup. Therefore any new technique to eliminate the suspended impurities from syrup would contribute to improvement in the quality of white sugar in as much as the sugar crystals developed in syrup containing suspended impurities are bound to contain higher amount of suspended matter.

4. JUICE CONCENTRATION AND SYRUP TREATMENT

4.1- Evaporation—As is now well established, maximum utilisation of vapours in the process operation leads to economy in steam consumption and attempts have been made in the recent past to install vapour cell, comprising one or two bodies, boiling juice at high temperature for supplying vapours of $105^\circ$ - $108^\circ$C to pans. The sugars in juice, particularly the fructose and glucose are highly sensitive to heat and decompose on prolonged heating to form caramel and other colouring matter. The time of contact of sugars with heat is an important factor in the colour development. Prolonged heating of juice at high temperature $100^\circ$ - $110^\circ$C affects the performance at crystallisation in two ways—
(i) colour content of syrup increases

(ii) sucrose is inverted leading to increase in glucose and fructose which are highly sensitive to heat.

It is thus of vital importance to avoid these conditions which would lead to colour development and impair the process performance while selecting suitable design of evaporator and the vapour cell as also the vapour withdrawal system.

4.2. Syrup treatment—In double sulphitation process syrup is sulphited as the crystal sugar is developed in the medium of syrup and the colour content of syrup can be brought down by SO$_2$. During sulphitation pH can be maintained at 5.2 - 5.4 and lowering the pH further by SO$_2$ treatment offers no advantages as far as colouring matter is concerned. The bleeching action of SO$_2$ in syrup is attributed by Zerban to blocking of carbohyl group of the reducing sugars which are responsible for caramel and melanoidin colour formation. For ensuring uniform treatments of syrup it is desirable to install pH controller for SO$_2$ treatment in a continuous system of operation.

The suspended matter % Bx increases from clear juice to syrup by 300% on account of some inorganic salts being thrown out of solution as shown by D.P. Kulkarni. $^5$ In 'A' massecuite boiling the suspended impurities which contain inorganic salts and organic matter are bound to get embedded in the sugar crystal. It is desirable to introduce separation of suspended matter by either centrifuging or filtration preceded by chemical treatment as it would bring down the ash content of sugar besides reducing the insoluble matter in sugar crystals.

5. CRYSTALLISATION AND SEPARATION

5.1. Pan boiling—The present established system of pan boiling for producing medium size (0.1.0 - 1.5 mm) sugar grains is as under—

(i) Only sugar from 'A' boiling is packed and marketed.

(ii) 'A' strikes are developed on sulphited syrup employing seed from single or double purged 'B' massecuites and melt from 'C' double purged sugar as also sugar from 'B' massecuites after meeting the demand for seed. 'A' light molasses of high purity around 90 is also used in boiling.

(iii) 'B' massecuite is built up on grain from 'A' heavy or in some factories on seed from 'C' double purged massecuites. The 'B' massecuite is single or double cured.

(iv) Usually intermediate massecuites between 'B' and 'C' as also the 'C' final massecuites are double purged and sugar melted, though at some places the well washed sugar from final massecuites is used as seed for 'B' boiling.

At the crystallisation stage the basic principles underlying the scheme of boiling for mill white sugar are—

(a) seed must be white, of well washed sugar, free from molasses,
(b) melt should be from well washed sugar,
(c) syrup has to be sulphited properly,
(d) pan boiling at all stages has to be carefully conducted so that the purging characteristics of all grades of massecuites particularly the 'B' and final massecuites are satisfactory in order to obtain good quality seed and melt of very low colour value.

White sugar of very small size which passes through 20 or 28 mesh screen of the sugar grader considered to be unmarketable constitutes good seed but the quantity is always inadequate and seed from 'B' massecuite curing has to be used. It is good practice to double purge 'B' massecuite strikes in order to ensure thorough separation of molasses adhering to sugar crystals. Care has to be taken to avoid prolonged boiling of 'A' strikes to avoid colour formation arising out of longer contact of sugar with heat.

5.2. Crystallisers and centrifugals—The 'A' massecuites are usually not cooled for more than 2-4 hours during plant running. Longer duration of cooling though favours molasses exhaustion might result in some colouring matter entering the outer crystal layer. As regards centrifugal station the old type of manually operated centrifugals have been completely abandoned in favour of high gravity machines with either complete automation or semi automatic system of operation. Single purging is preferable to double purging provided the separation of heavy and light run off is effectively regulated automatically. The operation of separator for these two run offs is to be so regulated as to give 'A' light of about 90 purity which can then be used in 'A' massecuite boiling. Failure of the separation system proves costly in that, lower purity 'A' light has then to be used in 'B' boiling thereby upsetting the purity control of massecuites. As regards melt quality—it can be maintained well when the lower grade massecuites are purged properly and the sugar is washed free of traces of adhering molasses in the centrifugals. The melt is usually of 94-95 purity and has water white appearance. In case the melt is prepared using clear juice it has to be sulphited properly along with syrup in which case the melt is not separately stored but is mixed with syrup.

6. BOLD GRAIN MANUFACTURE

In India large quantities of white sugar are produced with grain size of 1.2 - 2.0 mm employing mostly double sulphitation process, in response to consumer demand. Production of large grain size sugar without sacrificing lustre or whiteness which is being successfully practised in the country requires special care in respect of seed for boiling 'A' strikes, and also in the boiling procedures.

In the pan boiling there are two ways of increasing the grain size viz.

(a) developing fine seed in pan which is cut into another pan which is filled again and recut 3-4 times until the desired grain size is attained.

(b) Big grain seed is taken for 'A' pan and developed with one or two times cutting if necessary. Experience at Phaltan Sugar Works shows that cutting pans more than
three times for increasing grain size has deleterious influence on colour of sugar. It is therefore necessary to use 0.5-0.9 mm size sugar as seed for big grain strikes and since this size of small grain will not be obtained from bold grain boiling, intermittently strikes have to be boiled on 'B' sugar seed, from which good amount of 0.6 mm sugar in sizeable quantity can be obtained.

(c) Unnecessary drinks of water have to be avoided and careful check is essential on quantity of water fed to 'A' strikes during boiling. The time of boiling should be minimum and progress of boiling once commenced should not be hampered due to insufficient feed material.

(d) The pan design has to suit rapid boiling with good circulation characteristics.

(e) Special attention needs to be paid to the colour of melt and 'A' light apart from the syrup.

Capacity of pan station has to be higher when sizeable proportion (exceeding 30-40%) of the sugar grain produced is of larger than 1.2 -2.0 mm size. The total 'A' massecuite boiled per tonne of marketable sugar produced is bound to be higher with bold grain production since good amount of small size white sugar (below 1.2 mm) is to be put back in process as seed. The increase in load on 'A' boiling will depend on the proportion of big grain manufactured to total production of sugar. Usually two times, a pan is cut and the small grain produced is considerably reduced and when shortage of white small sugar seed occurs few strikes are boiled on seed from 'B' massecuite sugar.

At the centrifugals however large grain size favours easy separation of molasses even by employing less amount of wash water. If anything, the capacity of centrifugal increases to some extent with big grain strikes.

7. SPECIAL WHITE SUGAR

Attempts were made to produce special quality sugar by boiling 'A' strikes using white sugar as seed and developing it on melt from B and 'C massecuites, at Ravalgaon and later at Phaltan Sugar works Sakharwadi. The purity of these massecuites is around 95-97 while the run off after purging the same is of 92-93 purity. This system of boiling special melt massecuites can give uniformly good quality sugar irrespective of the variation in cane quality but involves additional load on boiling and the entire crystallisation station. The sugar produced is lustrous white and Factories desirous of adopting this system have to instal one pan, one crystalliser and two centrifugals as additional equipment for manufacture of a portion of their entire production as special white sugar by this method. Moreover steam requirement will also go up as a result of the extra load on boiling. Factories have to be guided by economic factors such as the financial benefits and capacity utilisation which should under no circumstances be adversely affected. In case the marketing conditions favour bold grain lustrous sugar and factories opt for this process they will have to install one pan with good circulation characteristics, one or two crystallisers and two centrifugals to be able to produce part of its total sugar manufactured, by boiling massecuites on melt only. The run off from these massecuites will have to be used in regular 'A' massecuite boilings.
8. COLOUR DEVELOPMENT IN STORAGE

Sugar produced in factories has to be stored in warehouses for months together during which periods atmospheric changes like hot summer months, humid rainy weather and cold winter are inevitable. In certain parts of India maximum day temperatures can be as high as 40° - 45°C. The crystal sugar of high quality must retain the lustrous appearance and whiteness during storage until it reaches the consumers but the white sugar produced by carbonation factories in India has undergone deterioration in colour during storage. Similar observations have been reported about sugar manufactured by conventional carbonation process in Taiwan. Compared to the juice sulphitation process the double carbonation offers distinct advantage in respect of consistently producing good quality white sugar under varying conditions of juice composition but as far as keeping quality of white sugar is concerned the carbonation sugar undergoes faster deterioration of colour than the sulphitation sugar which retains whiteness and lustre for a fairly long period. In the conventional double carbonation the juice after second carbonation at about 8 - 8.5 pH is neutralised with S0₂ and investigations by Parashar showed that the reduction of S0₂ in stored sugar is accompanied by development of brownish tinge particularly in hot periods. Work by Gundu Rao & Ramaiah demonstrated this development of colour to be due to slow caramel formation resulting from carbonates in sugar reacting with reducing sugars. Carbonation sugar is thus more susceptible to caramel formation due to presence of more alkaline carbonates as compared to sulphitation sugar since the carbonate content of the former is 8 to 16 times that in the latter. According to Ramaiah the carbonates of potash and sodium embedded in sugar crystals catalyse the carmelisation of reducing sugar.

To check this deterioration of colour the filtered juice of second carbonation was treated by phosphoric acid instead of S0₂ and refiltered. Work on these lines was carried out in Taiwan as well as India with perceptible improvement in the keeping quality of sugar produced. The phosphoric acid forms voluminous precipitate of tricalcium phosphate which offers large surface area for adsorption and occludes the colouring compounds as well as colloids. This phosphoric acid treatment however involves additional investment in terms of equipment like phosphoric acid treatment tanks and filters or subsiders besides extra costs incurred in use of phosphoric acid but has been found to yield positive results in respect of keeping quality of sugar. Yet another procedure to check the caramel formation suggested is to sulphite filtered juice after second carbonation to lower pH value in carbonation (up to 6.0) so that the carbonate content is reduced. However the phosphatation of second carbonation clear juice being proven on larger scale practice, appears to give positive results though its economics will need to be thoroughly worked out in each region as was done in Taiwan.

Sugar produced by double sulphitation process has not posed any serious problems related to colour development though extensive experimental data in this regard is lacking.
9. SIZE AND SHAPE OF CRYSTALS

Sugar crystals of regular shape and size possess better keeping quality. The two problems associated with shape and structure of sugar crystals which have a bearing on keeping quality are—

(i) conglomerate formation and

(ii) inclusions.

During pan boiling whenever supersaturation exceeds certain limits crystals join together and remain unseparable till the end of strike. These rolled or mounted grains are objectionable because impurities get lodged between the crevices of joined crystals which adversely influence the keeping quality of sugar. The inclusions in crystals are caused by variations in supersaturation of mother liquor in which the crystals are grown. Crystals are eroded in unsaturated medium and when regrowth commences impurities are trapped in the layers of crystals. The main cause of inclusion is the frequent variations in the concentration or the degree of supersaturations as also poor circulation of mass during boiling. Presence of higher amount of impurities in sugar crystals favours development of colour and moisture adsorption during storage.

Conglomerate formation takes place when supersaturation exceeds certain limits within which the existing crystals develop as a result of deposition of sucrose from mother liquor, and concentration of boiling massecuite is carried to undesirable extent in pan boiling. Likewise in pans with poor circulation characteristics conglomerate formation is evidenced due to pockets of very high supersaturation being generated and thus it is of utmost importance to ensure good circulation of massecuites in the pans by selecting suitable designs or by introducing mechanical circulators. Both these problems of inclusions in crystals and conglomerate formation can be overcome by adopting.

(i) automation in pan boiling and

(ii) installing pans with good circulation characteristics.

Since the conglomerates are composed of many crystals joined together irregularly in the interstices of which impurities are lodged, they always contain higher ash and other impurities than the well formed crystals, which adversely affects their quality and appearance. Composition of sugar crystals has a great bearing on the industrial use of sugar and one important way to bring down the impurities in crystals is to boil a massecuites in high purity medium in pan with good circulation characteristics and avoid inclusion or conglomerates.
REFERENCES


TABLE 1

COMPOSITION OF WHITE SUGAR FROM INDIAN FACTORIES AND Refined SUGAR

<table>
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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pol %</td>
<td>99.5</td>
<td>99.8-99.9</td>
<td>99.6-99.8</td>
</tr>
<tr>
<td>2</td>
<td>Moisture %</td>
<td>0.08 Max.</td>
<td>0.05</td>
<td>0.04-0.05</td>
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<tr>
<td>3</td>
<td>Reducing sugar %</td>
<td>0.1 Max.</td>
<td>0.02-0.03</td>
<td>0.04-0.06</td>
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<tr>
<td>4</td>
<td>SO₂ p.p.m.</td>
<td>70 Max.</td>
<td>20-60</td>
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<tr>
<td>5</td>
<td>CaO %</td>
<td>0.03</td>
<td>0.02-0.03</td>
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</tr>
<tr>
<td>6</td>
<td>Colour ICUMSA unit</td>
<td>30-50</td>
<td>100-200</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Sp. Conductance 5% soln. × 10⁸ mhos/cm</td>
<td>100</td>
<td>10-15</td>
<td>50-70</td>
</tr>
</tbody>
</table>
10. FINAL MASSECUITE BOILING AND TREATMENT FOR MAXIMUM EXHAUSTION

1. Evaporation of water from sugar containing liquors for obtaining sugar in crystalline form is performed at the pan station while the cooling of the mass containing crystals and liquor is effected in crystallisers. These two stations together complete the crystallisation of sucrose at the final massecuite stage, and assume, place of special significance in plant operation in view of the fact that 8-10% sucrose in cane is lost in the final stage of crystallisation. It is important to consider various natural as well as controllable factors which are responsible for the sucrose loss in final molasses since the low grade crystallisation aims at reducing this loss to as low level as possible.

In the case of final stage of crystallisation the entire system of pan boiling, crystalliser operation and centrifugal working has to be considered since the mother liquor from this system will be thrown out of process in the form of final molasses.

2. FACTORS AFFECTING MOLASSES EXHAUSTION

2.1. In view of the magnitude of loss of sugar in the final molasses it is essential to consider the factors responsible for the varying degrees of sucrose retention in molasses. Exhaustion of molasses, in this context means recovering maximum sugar from molasses under practical operating conditions. The problem of molasses exhaustion and the factors influencing the same have to be considered from two angles viz.,

(a) composition,

(b) operation in factory.

As regards the composition it must be borne in mind that the non-sucrose impurities in cane juice when leaving the process will inevitably carry some sucrose with them, the quantum of sucrose depending on the nature of impurities.

Moreover the nonsugar composition from cane juice undergoes modification in the process upto final crystallisation stage. In process operation the maximum recovery of sucrose can be achieved at the final crystallisation stage by adopting correct techniques and employing proper equipment.

2.2. Composition aspects—The non-sugars influence the molasses exhaustion in two ways—one is the retention of sucrose i.e. solubility of sucrose and second is the effect on rate of crystallisation.

In general the inorganic salts increase the solubility of sucrose while the reducing sugars
bring down the retention of sucrose in molasses. By far the most important factor determining the exhaustion potential of molasses is the reducing sugar/ash ratio. The higher this ratio, lower should be loss of sucrose in molasses. In India this ratio varies from 0.9 to 2.5 in different regions. The Table 1 gives the solubility of sucrose in water in the presence of invert sugar.

<table>
<thead>
<tr>
<th>Temp.</th>
<th>Invert sugar per 100 gms. of water</th>
<th>Solubility of Sucrose per 100 gms. of water</th>
<th>Solubility of sucrose per 100 gms. of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>50°C</td>
<td>0</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>242</td>
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</tr>
<tr>
<td></td>
<td>200</td>
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</tbody>
</table>

Beet molasses owes its high sucrose purity mainly to the presence of high ash and very little reducing sugars. Likewise the sugar producing areas where the reducing sugar/ash ratio is low the potential for bringing down the molasses purity is limited.

Along with solubility the rate of crystallisation deserves special consideration. The rate of crystal growth is governed by following conditions—

(a) rate of crystallisation increases with supersaturation and also with temperature.

(b) crystal growth is retarded by inorganic as well as organic impurities.

2.3. Working Conditions—In plant operation, the equipment and the technique of operation have both to play important role in reducing the loss of sucrose in molasses. In process operation the conditions which influence exhaustibility are—

(a) viscosity of massecuite

(b) crystal size and concentration

(c) purity and brix of massecuite

(d) recirculation of impurities.

3. CONTROLLABLE OPERATING CONDITIONS

In plant operation the quality of boiling and the technique adopted in the direction of achieving maximum exhaustion ultimately decide the loss of sucrose in molasses.

(a) Solid content—It is an established fact that degree of supersaturation has to be raised
in final massecuite for achieving high rate of crystallisation. The high brix massecuites are consequently favoured for better exhaustion.

High impurity to water ratio i.e. I/W in massecuite is an important consideration in the exhaustion of molasses. Simply stated it means that the purity of massecuite has to be as low as possible while the brix has to be as high as practicable. In consonance with this the recent trend in Indian industry is to lower down the apparent purity of final massecuite to 50 or even below as against the previous practice of dropping 'C massecuites of around 60 purity. There are however practical limits in operation; and attempts have to be made to lower down purity and water content of massecuite consistent with the capacity of equipment to handle the same.

(b) Viscosity—Viscosity is a dominant factor in the final stage of crystallisation and many times becomes a limiting factor in the exhaustion of molasses. Viscosity is the resistance to flow of a layer of liquid over the other and is measured in units of poises, one poise being a force required to cause two parallel surfaces of 1 cm$^2$ and one cm. apart to slide past each other at a velocity of one cm./sec. For most of the simple solutions viscosity force relationship is straight and these are perfect liquids. However some liquids exhibit plastic flow in that, initially resistance to flow is high when good amount of force is required to be applied to overcome this resistance. Final molasses exhibits pseudo plastic flow which indicates intermediate behaviour between the two. Massecuites show pseudo plastic tendency to a greater extent than molasses, particularly at high crystal content.

Certain impurities like gums, dextran and other colloidal matter contribute to viscosity; similarly higher the brix higher will be the viscosity of massecuite. Rise in temperature brings down the viscosity tremendously and at saturation temperature of molasses minimum viscosity is observed. This interesting property of minimum viscosity of molasses at saturation temperature is of practical importance and this temperature is reported to be nearly 55°C by different workers.$^3$

Work on relationship between gravity or true purity and viscosity by Mc Cleery, Kelly and Behne, at different saturation temperatures has proved that at the same viscosity lower molasses purities are observed at higher saturation temperatures upto 55°C$^4$. The practical significance of this work is that in boiling and crystalliser operation the massecuite of maximum viscosity should be produced, which will give molasses of saturation temperature of about 55°C.

Methods—

(a) Hoppler viscometer found wide application for molasses viscosity and was used at Java Sugar Experimental station for study of molasses exhaustion. It consists of an inclined transparent tube filled with molasses through which a ball is dropped. Thermostatic arrangement helps maintain constant temperature for measurement.

(b) Brookfield viscometer measures viscosity by the drag produced on spindle which rotates at constant speed in the molasses. The tension produced in a spring connected to spindle shaft is indicated on dial.
(c) Despite the suitability of rotating cylinder method for viscosity measurements of molasses as recommended by ICUMSA (16 and 17th Session), the problem of suitable technique for estimation of viscosity of massecuite remains unsolved. In Australia work was carried out on pipeline viscosimeter in which massecuite flows from a large diameter reservoir through small diameter tube of standard length, the pressure drop indicating the viscosity. Yet another method based on flow property of massecuite, is the orifice viscometer in which massecuite is allowed to flow from a rectangular tank through orifice. Flow rates are measured at constant temperatures. These methods are suitable for both molasses and massecuite and should find application in Industry.

In general it may be stated that—

(i) for a particular massecuite higher the viscosity, lower will be the purity of molasses,

(ii) viscosity of molasses is doubled with increase in total solids by 0.8%.

(iii) viscosity of molasses is reduced by 50% by raising temperature by 5°C.

Viscosity limits the workability of massecuite in pans and crystalliser and some surface active chemicals which reduce the viscosity by reduction of surface tension have been developed in recent years.

(c) Crystal content and size—The cry rate is higher with greater surface area. The surface area of crystals can be calculated from the crystal size and crystal content by the formula:

\[ s = \frac{19x}{l(100-x)} \]

Where: \( x \) represents crystal content and \( l \) is the length of crystal, in mm.

In the recent past, with the introduction of continuous centrifugals the trend towards reducing the crystal size to 0.2 mm in final massecuites has been established as against the previous practice of maintaining 0.3 to 0.35 mm which suited the batch machines in respect of separation of sugar from molasses. One limiting factor in size reduction of sugar crystals is the availability of pore space in the crystal bed for passage of molasses during centrifugal separation since as the crystal size diminishes the porosity goes down and resistance to flow of molasses increases tremendously. If for crystal size of 0.417 mm: relative pore cross sectional area is 100 it is reduced to 25 when crystal size is reduced by 50%. Thus in practice with high gravity centrifugals and the crystal size of 0.3 to 0.35 mm, good molasses separation is obtained. With modern continuous centrifugals the limit to the size of grain may be considered to be 0.2 mm.

In the context of efficient centrifugal separation uniformity of sugar grains is equally important in as much as the pore volume and the drainage of molasses is adversely affected with sugar crystals of different sizes, since the packed bed of crystals offers resistance to flow of mother-liquor.

For a given size of sugar crystal, the total crystal area will be determined by the crystal content of massecuite which is found out by the following equation.
% crystal in massecuite = Massecuite purity - molasses purity x Massecuite refractometnc Brix
100 - molasses purity

Thus the rate of deposition of sugar from mother liquor will depend on the total crystal area, for a given set of conditions and for a given size of crystals desugarisation of molasses will be more and faster when the crystal content is high. But as the viscosity of massecuite rises with crystal content and it is essential to maintain the concentration and viscosity as high as possible a practical limit is set to the crystal content of massecuite. It is therefore essential to maintain crystal content at highest level along with high viscosity of mother liquor for maximum exhaustion subject to the workability of massecuite in the crystallisers and centrifugals. Increasing the viscosity of massecuite and improving its fluidity and workability by addition of water is self-defeating in that the high viscosity is conducive to higher exhaustion of molasses whereas addition of water leads to redissolution of sugar and higher loss of sugar in molasses. Lower crystal content leads to less exhaustion in crystallisers and consequently lower purity drop.

Gillett's investigations on low grade crystallisation have shown following limits of solid liquid ratios in purging of final massecuites under Hawaiian condition at 50°C.\(^9\)

(i) solid phase true crystal volume—44% massecuite volume.
(ii) liquid phase to fill crystal void—36% —do— —do—
(iii) liquid phase surplus for fluidity 20% —do— —do—

Rate of crystal growth is accelerated by providing larger crystal surface area and thus small size of crystal in final massecuite is preferable to large size. Uniformity of crystal size is important for obtaining good purging and reducing recirculation of molasses.

(d) Recirculation of molasses—Higher the non-sugar content of forecured sugar of final massecuite higher is the recirculation of molasses. Taking 90 purity of final massecuite sugar as the ideal the amount of recirculation with decreasing purities will be as in Table 2.

4. PRACTICAL ASPECTS OF PLANT OPERATION

4.1. Exhaustion indicates the sugar in crystals in a massecuite out of 100 sugar in massecuite and can be estimated from—

\[
\text{exhaustion} = \frac{100}{\text{sugar in massecuite}} \times \text{Ref. solids in massecuite} \times \frac{\text{Py of massecuite} - \text{Purity of molasses}}{100 - \text{purity of molasses}}
\]

\[
= \frac{100^2}{\text{Purity of massecuite}} \times \frac{\text{Purity of massecuite} - \text{Purity of molasses}}{100 - \text{Purity of molasses}}
\]

According to Perk this value should be above 60 for any type of massecuite.\(^{10}\)
The state of exhaustion of molasses in practice is known from the purity obtained and the target purity according to exhaustibility tests.

Micheli and De Gyulay proposed the equation of exhaustibility as

\[ E_0 = 100 - P_1 \]

Where: \( P_1 \) is the lowest true purity obtainable in exhaustibility test

State of exhaustion is relation to exhaustibility in the following way—

\[ E = \frac{100 - P_2}{100 - P_1} \]

\( E \) = State of exhaustion.

\( P_1 \) = lowest purity according to exhaustibility test

\( P_2 \) = actual purity of molasses.

4.2. Usually three-massécuite system is followed in Indian Industry but when the purities of juice are very high i.e. above 85-86, an intermediate massécuite between 'B' and 'C' is boiled for bringing down the final massécuite purity to 50-52. After a number of actual boiling trials each factory can decide the lowest purity of 'C' or final massécuite which gives minimum loss of sugar under plant operating conditions and resort to 3 or 3-1/2 massécuites or even 4 massécuite boilings to maintain the same. Needless to state the design of pan, crystalliser stations must take this factor into account. In areas where the raw-juice purities exceed 85-86 during peak recovery period the 'A' massécuites of 88-90 purity are dropped and it is essential to adopt 3-1/2 massécuite system since good exhaustion at 'A' and 'B' massécuite stages will permit maximum total drop of 36 to 39 units from 'A' massécuite to 'B' heavy which will not be adequate for bringing down 'C' massécuite purities to low levels.

4.3. Final massécuite purities—It is desirable to bring down the final massécuite purities as much as possible keeping in view the limits set by the workability of massécuites in pans, crystallisers and centrifugals. Under conditions of high ratio of R.S./Ash and low operating viscosity it is advantageous and practical to reduce the final massécuite purities to 50-52 or so as demonstrated by the practices followed in several factories, particularly in Tamilnadu. For bringing down final massécuite purities to the limits of workability it is essential to—

(a) keep graining medium purities low, by use of 'C' light and 'B' heavy

(b) ensure low purities of 'B' heavy by proper concentration of 'B' massécuites and cooling the same. Use of continuous centrifugals for final massécuite purging results in higher 'C' light purities—60-62 or so and for ensuring low purities of final massécuite it is essential to get 45-47 purity molasses from penultimate strikes. Under no circumstances should 'C' light be fed back to earlier strikes i.e. 'B' strikes.

(c) maximum exhaustion has to be aimed at in the pan itself which calls for rigid control on purities of feed to the pan and tight boiling.

(d) since supersaturation is the driving force in crystallisation tightening the final
massecuites to as high concentration as possible is very essential. The highest possible brix of final massecuite has to be determined by each factory to suit the equipment.

5. GRAINING

In the entire scheme of pan boiling as practised in modern plants no nucleation is allowed to take place at any stage including graining and only seeding is adopted for preparing grain footing. Final massecuite graining ceased to be an 'art' requiring special skills after introduction of seeding method. The present seeding technique requires the introduction of fine grain sugar of 3 to 5 micron size in non-aqueous medium into the molasses in the pan, which has been concentrated to the point of developing the grains. Solvents to be used for slurry should have low viscosity and lower boiling point than water and ethanol or isopropyl alcohol are commonly used. According to Chen \(^{13}\) Polyethylene Glycol is preferable to isopropyl alcohol for obtaining stable sucrose suspension while using icing sugar.

In proper graining method following steps are involved—

(i) The final grain size of 'C or final massecuite is to be maintained at 0.18 - 0.2 mm. while the slurry seed should be of 3 to 5 micron size. Sugar from sugarhouse has to be mixed with the solvent and ground in ball mill for attaining this size. The grain footing should be planned for 2-3 strikes and quantum of slurry should be determined on the basis that only the original grains will be developed. The weight of seed sugar to be charged can be calculated for a 100 t. total strike as follows—

\[
\text{Wt. of seed} = \frac{\text{Weight of 500 crystals of seed}}{\text{Weight of 500 crystals of massecuite}} \times \text{weight of sugar from 100 t. of strike.}
\]

It is desirable to feed slight excess quantity of slurry to pan at the time of seeding.

(ii) The charge in the pan should consist of 'C light, mixed with 'A' heavy and 'B' heavy with a purity of around 63-65 and concentrated to a supersaturation which does not permit nucleation or dissolution of slurry grain. This point of feeding is best determined by use of conductivity instrument and the optimum conductivity readings should be determined after careful trials.

(iii) The grain is hardened with occasional but regulated drinks of water.

(iv) Hardening is followed by drinks of 'A' heavy C.L. and 'B' heavy so as to fill the pan with footing of 58-62 purity.

(v) the footing is cut into vacuum crystalliser, for either one or two strikes depending on the quantum of slurry seed used at graining.
6. BOILING THE STRIKE

6.1. In boiling the strike supersaturation has to be gradually raised as the purity goes on decreasing as a result of 'B' heavy feeding. In practical terms this means tight boiling with regulated feed of well conditioned molasses. The feed has to be of about 70° Bx and preheated to 70°C, and free from sugar crystals in suspension. After the pan is filled, the molasses feed is to be stopped and drinks of water given while the strike is getting thicker. Nearly one hour’s tightening is helpful in bringing about good pan exhaustion. The final brix of 100° - 104° of final massecuite should be maintained with proper tightening at the end. Use of instrument like conductivity meter is of utmost importance for the pan boiler. Similarly viscosity reducing chemicals should be added during boiling particularly at the final stage of the strike. The strike is dropped from the pan into the crystalliser only after the desired low purity of strike is obtained.

6.2. Equipment—At the pan stage the vacuum pan should have good circulation characteristics so that even at high strike levels the circulation of mass and evaporation rate are maintained well. A mechanical circulator in a pan boiling final massecuite is of great assistance in this behalf, which in effect not only maintains high rate of circulation and evaporation but also brings down the total time of boiling.

Instruments have to be fitted to pans for observing temperature, vacuum and conductivity or degree of supersaturation as without the help of these, boiling on scientific lines for obtaining good pan exhaustion is practically impossible.

Molasses conditioning equipment for diluting and heating the 'B' heavy, 'C light molasses, for dissolution of fine sugar grain has now become quite common. However, the heating and dilution should be automatically controlled as far as possible.

For slurry preparation a ball-mill has to be installed on the pan-floor.

Vacuum crystalliser for cutting the grain footing serves useful purpose of reducing the graining operations and control of massecuite purities and it should have adequate capacity.

6.3. Pan boiling control and instrumentation—As stated earlier the supersaturation state is essential for crystal growth and the region of supersaturation is divided into three zones viz.,

(a) metastable,
(b) intermediate and
(c) labile:

In 'C nucleation takes place giving rise to formation of new grains while in

(a) i.e. metastable zone only existing crystals grow. The intermediate phase is conducive to growth of crystals as well as new grain formation. It is thus imperative to conduct the pan boiling operation in metastable zone and instruments which help maintain the required degree of supersaturation for achieving the desired rate of growth in the metastable phase are indispensable in the control of pan operation. Various instruments in vogue have been described elsewhere.
7. CRYSTAL VOLUME

7.1. High crystal content in final massecuite favours exhaustion but it also leads to high viscosity and in practice the crystal content has to be adjusted at highest level and with high viscosity of mother liquor the massecuite will give the highest viscosity consistent with workability in the factory equipment at the crystallisation station and centrifugals. Realising the influence of true crystal volume on the massecuite fluidity Gillett evolved a practical method for estimating crystal volume by use of the concept of apparent crystal volume employing a simple device, and establishing relationship between apparent and true crystal volume.

7.2. Apparent volume and true volume of crystals—The apparent crystal volume of 'C'massecuite is determined in a special apparatus by application of hydraulic pressure. Surplus molasses besides that which fills the voids of crystals, but has the function of improving fluidity of massecuite is separated. A container with piston, centrifugal screen at the bottom and a scale are the components of this apparatus. The known quantity of massecuite filled in cylinder is compressed by plunger upto a pressure of about 2.7 kg/cm² and the molasses extracted through the screen is the surplus fluid. The liquid which fills the pore space in the crystal bed is unaffected. The surplus liquor percentage is termed as shrinkage factor while the compacted crystal volume represents the apparent volume of crystals.

Gillett has worked out relationship between apparent and true crystal volume as given in following table.

<table>
<thead>
<tr>
<th>% True crystal volume in massecuite</th>
<th>% Apparent volume in massecuite</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>20</td>
<td>36</td>
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<tr>
<td>30</td>
<td>55</td>
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<td>35</td>
<td>64</td>
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<td>73</td>
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<tr>
<td>45</td>
<td>82</td>
</tr>
<tr>
<td>50</td>
<td>91</td>
</tr>
</tbody>
</table>

With low grade crystallisation in refinery, the following ranges of values of apparent crystal volume at different stages were found.

- Good pan boiling: 40-60%
- Maximum for charging crystalliser: 60-70%
- Maximum for charging centrifugals: 75-80%

The middle values represent the most favourable condition. Nevertheless it needs to be
emphasised that the values of apparent crystal volume favourable for maximum exhaustion of molasses need to be determined in every sugar producing region in view of the recent developments in the use of continuous centrifugals which can handle very well the massecuites with small grain size of 0.15 to 0.2 mm. as also the recent techniques of dropping low purity 'C massecuites.

8. CRYSTALLISERS

8.1. The massecuite boiled in pans is dropped into crystallisers which play complementary role in recovering extra sugar from mother liquor. Maximum purity drop from massecuite to molasses has to be aimed at in pans; however 12-20% drop can be achieved in cooling of 'C massecuite in crystallisers from 65° - 70°C to 40°C. Cooling of 'C massecuite thus accounts for 3-5 units reduction of purity of molasses as the sucrose from mother liquor slowly deposits on the crystals present in the massecuites. As the impurity concentration in mother liquor rises the rate of crystal growth is considerably reduced as shown by Silin\(^16\) that the rate of crystal growth in beet sugar solution of 55 purity is about 64 times slower than in pure sugar solution. Therefore time element assumes significance in the crystalliser operation and usually about 20 to 24 hours' time is provided for massecuite, in water cooled crystallisers for completing the crystallisation work. As cooling proceeds, the viscosity of massecuite gradually increases and the equipment has to be sturdy enough to handle the same.

8.2. In operating water-cooled crystalliser, after dropping a strike cooling water is turned on after two hours, until the massecuite reaches 40°C, when the massecuite becomes highly viscous. After the minimum temperature is reached the water circulation is stopped and crystallisation is allowed to continue for 2-3 hours. The massecuite is thereafter reheated to 52° - 53°C for reducing the viscosity and improving purging characteristics at the centrifugal station.

In batch type of crystallisers this complete cycle of cooling and reheating of massecuite has to be carefully carried out in the case of each strike. The reheating of massecuite is effected by passing hot water of about 55°C through the revolving elements of the crystalliser. Normally with a cooling rate of 1.5°C - 2°C per hour sixteen hours would be required for the massecuite to reach 40°C. While circulating hot water the temperature of water should not be more than 2°C above the saturation temperature of molasses, which lies between 52°C - 55°C.

8.3. Continuous crystallisers—A system of continuous crystallisers is always preferred to batch operation as it leads to controlled cooling and reheating of final massecuite and yields consistant results. The existing battery of batch crystallisers can be converted into a continuous crystalliser by interconnecting the same by means of wide gutters at the alternate ends of adjoining crystallisers. The system should comprise—

(a) receiving air-cooled crystalliser for final massecuite,

(b) continuous crystalliser units with cooling elements,
(c) reheating arrangement for massecuite.

The capacity of receiving crystalliser should be sufficient—

(i) to allow continuous flow of hot massecuite into the (b) and

(ii) to keep space for fresh strike to drop intermittently from the pans.

8.4. In the design of any continuous system involving flow of viscous thick mass, plug flow of material assumes special significance. In South Africa and Australia studies employing radio active tracer technique have thrown light on the deficiencies in the design. So far however no such work has been undertaken in the Indian industry. However it is essential to provide sufficient baffles and ensure that no dead pockets are formed in the continuous crystalliser.

8.5. Reheating in crystalliser by circulating hot-water results in rise in purity of molasses by 2 - 2.5 units on account of dissolution of crystals in the crystalliser. Introduction of 'Transient' heater developed by Dr. K S. G. Doss, which consists of stationary heating elements over which cooled massecuite is allowed to flow has proved to be very useful to the industry in that reheating by this method avoids redissolution of sucrose and rise in molasses purity therefrom. A transient heater should be installed at the outlet of the continuous crystalliser.

8.6. Vertical crystallisers—In the last 7-8 years vertical continuous crystallisers of different designs have been installed for final massecuite cooling. They have the merit of occupying less space as compared to horizontal crystallisers. However unbiased studies regarding the flow pattern of massecuite as well as the exhaustion achieved, are required to be carried out with these systems. The massecuite as it gets cooled has to travel upwards to a height of 6-7 meters in these crystallisers.

9. CENTRIFUGALS

In most of the modern plants continuous centrifugals of large size have been installed in place of batch machines. These high gravity centrifugals, with gravity factor of upto 2000 have made it possible to boil small grain final massecuites and thus contributed substantially to improvement in overall performance of low grade crystallisation. It is desirable to use dilute molasses in place of wash-water in these machines. The capacity and performance of these machines can be further improved by interposing transient heaters between pugmill and centrifugal for ensuring reduction in viscosity. The screens fitted to these centrifugals have an aperture of 0.06 mm. Some factories have tried to use screens of 0.04 mm, slot opening with advantage. It is now well established that continuous centrifugals are more suitable for final massecuite curing than the batch machines in view of their ability to handle small grain strikes and produce consistently high purity 'C sugar.
10. LAYOUT OF THE CRYSTALLISATION SECTION

Gravity flow system of boiling house with three-storeyed structure is now accepted as more suitable than the two storey type since the former eliminates pumping of massecuites. A model layout of plant with installations of continuous crystallisers and continuous centrifugals should incorporate following features—

(i) To facilitate flow of thick massecuites from pans to crystallisers as well as from outlet of continuous crystalliser to centrifugal the gutters should be wide and should have good slope.

(ii) The space between pan platform and crystalliser top should be sufficient to permit installation of 'C strike receiver.

(iii) The height of pugmill of centrifugals from the machines should be sufficient to accommodate a Transient Heater.

11. OPERATIONAL CONTROL OF CRYSTALLISATION

In view of the importance of this section, in the context of the need to minimise loss of sugar in manufacture collection of data based on different analyses is very essential. For this purpose besides the routine analyses following data should be collected and records maintained for the same for efficient operational control—

(a) Pans—

(i) Grain size at graining and after the strike is dropped,

(ii) Nutsch purity of mother-liquor at the time of pan dropping,

(iii) apparent crystal volume may be determined off and on.

(b) Crystallisers—

(i) Temperatures of cooling and reheating water

(ii) Temperatures of massecuites at the inlet and outlet of crystallisers,

(iii) Temperatures of reheated massecuites.

(iv) Nutsch purities of molasses from cooled and reheated massecuites.

(c) Centrifugals—

(i) Purity rise on account of grains passing through screens,

(ii) Pol of 'C single purged sugar,

(iii) Quantity and temperature of water or dilute molasses employed for washing.

Regular analyses of composite samples of final molasses for various inorganic constituents and sugars will throw light on the exhaustion potential of the same. True purities may be determined for this purpose.
12. EXHAUSTIBILITY STUDIES

These studies aim at finding out target purity of molasses; which can serve as ideal for a certain region. In the exhaustibility tests or boiling down tests, molasses from factory is concentrated under vacuum in a special laboratory crystalliser and seeded with weighed amount of sugar. Further exhaustion is carried out for long periods over two weeks at room temperature. The molasses freed from sugar crystals is analysed for true purity, reducing sugar, ash and other non-sugars.

In Hawaii boiling down tests are carried at three different viscosities and crystallisation is carried out at room temperatures until saturation temperature below 50°C is reached. The samples are then filtered and analysed. The exhaustibility studies conducted in different countries have led to the development of relationship between target purities and composition of nonsucrose constituents. Most of the formulae incorporate reducing sugars, ash and non-sugars separately or R.S./non-sugar ratios. Work in India by Gupta and Ramaiah has shown that the equation for target purity should contain reducing sugar/ash ratio and not separate figures of reducing sugars and ash.

It is absolutely essential to carry out boiling down tests for molasses of each region for arriving at target purities. The difference between target or expected purity and actual purity is an indication of state of exhaustion.

TABLE-2

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Pol of Sugar</th>
<th>N.S.</th>
<th>Sugar</th>
<th>Total Quantity</th>
<th>Ratio of quantities to 1</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>90</td>
<td>10</td>
<td>15</td>
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</tr>
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<td>78</td>
<td>22</td>
<td>33</td>
<td>55</td>
<td>2.2</td>
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</tbody>
</table>

Note—C light of 60 purity.

13. PROCESS CONTROL FOR MOLASSES EXHAUSTION

It is an accepted fact that some sugar is bound to be inevitably lost in final molasses and every endeavour is necessary to bring down this sugar loss by observing certain precautions not only at the final crystallisation station but even in the operations proceeding this stage. These can be stated briefly as under—
(a) Clarification—Maximum elimination of nonsugars is to be achieved in juice treatment since nonsugars are the main cause of molasses formation. Similarly no salts are added to mineral matter already present in mixed juice during chemical treatment and reducing sugars are neither destroyed nor produced at the expense of sucrose.

(b) Evaporation—Decomposition of sucrose as well as reducing sugars due to longer retention of juice at high temperature is to be avoided.

(c) Crystallisation—

(i) Maximum exhaustion should be aimed at in 'A' and 'B' boilings by maintaining high brix of massecuites in pans and cooling them in crystallisers.

(ii) Recirculation of sugars and nonsugars has to be minimum and particular attention needs to be paid to proper separation of molasses from 'C' sugar so as to maintain purity of 'C' forecured sugar above 80. Likewise separation of A heavy from A light has to be perfect in single curing of A massecuites.

(iii) 'C or final massecuites of sufficiently low purity and highest possible brix should be boiled. When the juice purities are high intermediate massecuites should be boiled between 'B' and 'C' for producing 'C' massecuites of low purity.

(iv) 'C massecuites should be cooled to about 40°C and subsequently heated to 50° - 52°C in reheaters. Continuous crystallisers are more suitable for completing crystallisation operation. Reheating of massecuite should be carried out in equipment in which redissolution of sugar does not take place. No addition of water for improving mobility of massecuite in crystalliser is desirable. If required final molasses may be added for lubrication purpose. Modern continuous centrifugals are very helpful in handling 'C massecuites of low purity.

(v) Capacities of different equipment at pans, crystallisers and centrifugals should be adequate to handle the maximum 'C massecuite expected when raw juice purities are low and total amount of nonsugars entering boiling house are highest. The pans should have good circulation characteristics and should preferably be equipped with mechanical circulators. This is significant for boiling high brix 'C massecuites as the usual experience shows that poor circulation at higher levels of strike results in slow and uneven development of crystals. The continuous crystallisers should be checked for pockets of stagnant massecuite which can be rectified by installing suitable baffles.

(vi) Operating conditions with respect to pan vacuum and steam pressure have to be steady as variations in vacuum can lead to change in supersaturation and poor circulation of massecuite, which is equally objectionable. Normally high vacuum 660 - 685 mm. is desirable but under certain conditions lower vacuums accompanied by high temperature of boiling have been reported to be beneficial for attaining better exhaustion in pan and obtaining lower purity of molasses. However higher temperatures lead to more colour formation which is undesirable.
REFERENCES

3. Ibid p.299.
8. Ibid p.500.
11. SUGAR STORAGE

1. PACKING

Commercial white sugar is packed in 100 Kg. bags of hessian in the Indian industry but in other countries paper bags or 50 Kg. jute hessian bags are also used. In region with humid climatic conditions polythene lined hessian bags are preferred for better preservation of sugar from ingress of moisture. It is essential to get rid of iron specks from sugar before packing by attaching a magnet at the chute from which sugar flows into packing bags. The bags after filling are weighed accurately and sent to warehouse after closing the open end. The practice of hand sewing the top seams of bags with hemp twine is slowly being replaced by mechanical stitching. Stitching is preceded by accurate weighing on a platform type weighing scale in Indian industry. Since transport to warehouse for storage is carried out only in day time, the sugar packing house must be designed to accommodate the filled bags of sugar produced in the remaining 14-16 hours of the day.

In the sugar house where sugar bags are filled and weighed, the equipment usually installed is as under:

(i) Sugar grader with screens of different openings which receives sugar from the hopper through an elevator provided with 3 or 4 chutes from which bags are filled.

(ii) Magma mixer with suitable magma pump, for reprocessing of fine sugar or unwanted sugar, fine sugar magma being sent as seed to pan floor seed crystalliser while the unmarketable sugar is melted in the melter located behind centrifugals.

(iii) Sugar dust collector is connected to the top of grader for recovering dust which is collected in bags and melted. Sugar dust collector serves threefold purpose

(a) it prevents loss of sugar, though small in proportion to total production,

(b) sugar dust is explosive and poses danger as it spreads all around

(c) it pollutes the atmosphere in sugar house where number of workers are carrying out different functions, connected with packing of marketable sugar.

(iv) Weighing scales and bag stitching machine if the stitching is not manually carried out by workers.

(v) Small belt conveyers or portable trolleys for conveying bags from grader to weighing scale.

In plants not producing more than two grades of sugar it is possible to store the overnight production in steel silos which are emptied during day time when packing and weighing operations are conducted.
2. WAREHOUSING

In regions where the crushing campaign is restricted to 4-7 months in a year as in the case of Indian Sugar Factories, the sugar mills have to make provision for storage of nearly half the year's production in well constructed godowns. The weighed and stitched sugar bags are conveyed to the godowns on a belt conveyor from the sugar house and arranged in stacks of nearly 7-8 m height. The stacks are separated on the basis of grades as also quality and at the time of sale the bags are removed from stacks, care being taken in handling bags to avoid physical damage. In respect of warehousing following points need special attention of the factories—

(i) The godowns have to be located near the sugar packing house but away from the place where the filtercake is discharged from clarification house, as also at a safe distance from molasses storage in view of the fact that filtercake dumps or molasses tank surroundings serve as breeding places of all sorts of microorganisms. Similarly in relation to spray pond the location should be such as to prevent moisture laden air from entering the godown.

(ii) The warehouses are constructed on raised ground with proper arrangement for drains, away from factory water channels.

(iii) The roof of warehouse is constructed of corrugated sheets with proper slope to allow easy drainage of rain water, care being taken to arrange longitudinal overlapping of the same and to prevent ingress of water under any circumstances.

(iv) Flooring of godown has to be of sturdy construction to withstand the weight of large stacks of sugar bags and must be constructed in such way as to prevent seepage of water. The side walls should be coated with waterproof compound upto a height of about 1 to 1.5 meters from the ground floor.

(v) The openings of the godowns should be as few as possible and windows are undesirable. The main openings are fitted with rolling shutters.

(vi) It is desirable to prevent ingress of water whether through the bottom of the floor or sides and the floor can be covered with synthetic plastic sheet over which the sugar bags are placed. Similarly the top of each sugar stack is covered by water proof plastic sheet. Formerly wooden planks duly supported on beams used to be laid on the floor for supporting the bags but now a days it is common to find synthetic waterproof sheets being used to cover the floor.

(vii) Lanes of 0.5-0.7 m width are provided near the warehouse walls inside the godown and the bags should accordingly be stored somewhat at a distance from the side walls to protect the same from variations in temperature of the walls. The bags are stacked in accordance with grades upto a height of 7-8 m leaving open space of about 2.5 - 3 m below the roof. To avoid damage to the bags of lowermost layers it is advisable not to exceed this height of stack.

(viii) Regarding providing ventilation for the warehouse there are two aspects which need careful examination. In case of white sugar, prolonged exposure to atmosphere with
relative humidity of > 75—85 will result in damage to sugar. In case there are some areas in the godown where the air is not displaced local pockets of high humidity regions could be formed which would spoil the sugar bags, kept in such pockets. In factories located in high rainfall regions this problem assumes serious proportion. In low rainfall areas with comparatively smaller number of wet days it may be possible to prevent contact of sugar bags with humid atmosphere by providing no ventilators but only observation windows besides the usual doors. Under such conditions during dry weather free air should be allowed through doors and other openings while on rainy days the warehouse should be opened only when necessary. However, taking both these aspects into account as also the experience at several places it is advisable to provide sufficient ventilators which are to be operated for displacing the air inside the warehouse and preventing local pockets of humid air. For this, the ventilators have to be fitted such that no leaks of air occur when they are closed and these are easily operated. In this connection, the design of godown ventilators suggested by Phansalkar et al, which is of double panel type with both panels fitting tightly on leakproof rubber gasket can be adopted. Such panels should be fitted with necessary levers for operating them mechanically.

One of the methods adopted or suggested for maintaining low humidity in sugar godown is to keep quick lime spread at few places, which will need replacement frequently as lime absorbs moisture.

The stacks of sugar bags can also be protected to some extent from humid atmosphere by covering them with sheets of synthetic waterproof material.

It is desirable to maintain a record of temperatures and humidity in the warehouses in order to understand the fluctuations in weather conditions.

3. FACTORS AFFECTING KEEPING QUALITY

3.1. Moisture in sugar : Moisture content of sugar crystals plays vital role in determining its preservation without deterioration. The moisture or water associated with sugar is of two type (i) free or unbound water (ii) bound water. The white sugar leaving the centrifugals, contains around 0.2 to 1% moisture which is brought down to 0.03-0.04% i.e. the acceptable level on the long grass hoppers or in dryers. The water associated with sugar crystals and removed due to this drying is the free water while bound water is the residual water which is determined by elaborate procedure of drying sugar. Each sugar crystal is surrounded by a thin film of syrup which is in a highly supersaturated state, in which crystallisation can continue to take place for a long time.

When sugar is exposed to atmosphere moisture migration can take place either way i.e. either from air to sugar or from sugar to atmosphere depending upon the relative humidity of the air surrounding the sugar and soon an equilibrium is established between water vapour in surrounding air and the moisture of sugar. In this state of equilibrium no exchange of water from either sugar to air or air to sugar can take place as the vapour pressure of air and that of the thin syrup film surrounding the crystal are the
same. The vapour pressure of pure water increases with temperature and vapour pressure of aqueous solutions is always lower than that of pure water at the same temperature the difference increasing as concentration in solution rises. When weather is extremely humid with atmospheric relative humidity of 100% or thereabout the stored sugar will absorb moisture but when the humidity drops considerably i.e. during dry weather period the moisture in sugar will evaporate. In any case this transmigration of water resulting from hygroscopic nature of sugar continues until equilibrium is attained between the vapour pressures of surrounding air and sugar. Powers introduced the concept of equilibrium relative humidity (E.R.H.) which signifies the state of equilibrium between the atmospheric relative humidity and the sugar. The E.R.H. for raw sugar or white sugar which would keep well without undergoing deterioration depends on the amount of impurity in the sugar crystals. For pure crystal sucrose E.R.H. has been stated to be around 83% impurities depending on the temperature while the corresponding value for refined sugar is lower than that for pure sucrose. In the case of plantation white sugar very little work in finding out the E.R.H. under different conditions of manufacture is reported but it is expected to lie somewhat below the ERH value of refined sugar.

3.2. The nature of crystals and composition of white sugar exert profound influence on the keeping quality and moisture absorption or moisture release. Formation of conglomerates or twin crystals which are essentially small joined crystals, or crystal inclusions produced on account of lack of control over crystal development in pan boiling, result in more impurities being associated with sucrose crystals. Moreover the composition of medium of crystal growth which is composed of syrup. A light molasses and melt with respect to impurities, will always be decisive in the absorption and desorption of moisture from the atmosphere. The ERH value of pure sucrose has been found to be

\[
\text{ERH value of pure sucrose} = \begin{cases} 
85.5 & \text{at } 20^\circ\text{C} \\
84.0 & \text{at } 30^\circ\text{C} \\
83.0 & \text{at } 40^\circ\text{C}
\end{cases}
\]

This value will be lowered with increase in impurity content of crystals and thus will decrease from pure sucrose to refined sugar, and mill white sugar and finally raw sugar in that order. With lower ERH resulting from higher amount of impurity content, the sugar will absorb moisture at lower relative humidity of surrounding atmosphere. Out of the non sucrose impurities influencing the hygroscopic nature of sucrose crystals are reducing substances and some inorganic salts notably the MgCl\(_2\), CaC\(_2\), KCl and MgSO\(_4\). According to Cheng and Cheng hygroscopicity of sugar increases with increase in moisture as also reducing substances and decrease in the pH value of sugar. Similarly sugar of small crystal size absorbs more moisture than that containing bigger size crystals mainly because the former offers greater surface area for moisture absorption. This is in conformity with the common experience that small grain sugar is prone to moisture absorption and caking due to variation in atmospheric humidity. Surface active substances also contribute to hygroscopicity of sugar. Presence of comparatively large amount of reducing substances and low pH value are considered responsible for higher
hygroscopicity of cane sugar as compared to white sugar from beet, though both may be of very high polarisation.

4. CAKING OF SUGAR

Caking of sugar in bags is a phenomenon associated with external factors like weather conditions as also the nature of sugar crystals. If sugar, due to its hygroscopic character is exposed to atmospheric conditions of high relative humidity it will absorb moisture. Similarly the sugar crystals part with the moisture whenever they come in contact with atmosphere of low relative humidity. In consonance with this, whenever packed sugar which contains originally high moisture or has absorbed moisture after packing is exposed to atmosphere of low relative humidity the syrup film surrounding the sugar crystals parts with some of its moisture and reaches zone of high supersaturation. The sugar crystals being closely packed, crystallisation in the film results in joining of sugar crystals eventually leading to cake formation. The blocks of sugar cakes are difficult to dislodge from the packing bags and present problems in marketing. The factors favouring the cake formation of sugar crystals are—

(a) small grain size

(b) higher impurities in sugar crystals like reducing sugars which contribute to the hygroscopic character of sugar

(c) higher initial moisture of sugar at the time of packing than specified (> 0.04%)

(d) higher relative humidity of atmosphere followed by dry weather conditions of low R.H. In the absence of any remedial measures in the case of caking of sugar following preventive measures are essential.

(i) Sugar should be dried well which means efficient removal of unbound moisture.

(ii) Prior to packing, sugar must be cooled to 38°-40°C. since hot sugar bagging leads to cake formation.

(iii) In view of the role of impurities like reducing sugars in increasing hygroscopicity of white sugar, in the process every effort is essential to minimise the impurities in sugar crystals.

(iv) Small grain size favours moisture absorption and in case the grain size is to be maintained small to suit market needs, special attention needs to be paid to—

(a) minimum impurity levels

(b) avoiding conglomerate or twin crystal formation

(c) efficient drying and cooling

(d) avoiding exposure of sugar bags to large variations in atmospheric humidity.

(v) Irrespective of the size of sugar grain, the proper grading of sugar has to be taken care of to avoid mixing of different size grains.
5. SUGAR LOSS DURING STORAGE

Under Indian conditions the sugar losses experienced by the factories during storage of sugar in godowns can be attributed to—

(a) sugar loss during prolonged storage arising out of quality deterioration even though the external condition of packing is satisfactory.

(b) Damage to sugar bags in the warehouse during storage for over 6-8 months or so which can be as high as 0.2 to 2% of the total production.\(^6\)

The first one i.e. pol loss or colour development is essentially connected with process operating conditions which have been discussed elsewhere. In brief it may be stated that in process control, the factor of preservation of sugar during storage also must receive sufficient attention.

As regards losses occasioned by inadequate storage precautions or unsatisfactory warehouse conditions the usual experience of the factory technologists in India is that most of the sugar loss during warehousing takes place on account of—

(a) physical damage to bags during handling

(b) height of stack exceeding safe limits

(c) lack of precautions for preventing ingress of water on wet days from outside.

All the damaged sugar is collected and put back in process by one or a combination of 2-3 methods like—

(a) melting,

(b) adding to 'A' messecuite crystallisers or

(c) if it is in dry and good condition by mixing with freshly produced white sugar on the grass hoppers.

Handling damaged sugar and reprocessing it involves sugar loss which can be substantial.\(^7\) Moreover additional expenditure has to be incurred on labour, steam etc. and the eventual monetary loss is quite high and hence needs to be avoided by preventive measures.
REFERENCES

4. Ibid p. 91.
12. STORAGE OF MOLASSES

1. The mother liquor from the last stage of crystallisation, from which sugar cannot be economically recovered is termed as final molasses. This molasses is a thick and highly viscous liquid which has to be stored and preserved in large tanks for disposal, to meet the demands of molasses based industries. From commercial angle molasses storage has vital importance in view of its revenue earning potential. Every sugar mill has therefore to make suitable arrangements for proper storage of molasses such that both qualitative and quantitative losses are avoided and no molasses is allowed to flow either into public water streams or on soil, in view of its acidic nature and high fermentable sugars. The quantum of molasses produced by a sugar mill is around 30-40% of the total sugar produced in a crushing campaign.

1.2. Physical Characteristics—Final molasses is thick liquid of dark brown colour usually containing 80-85% solids in solution and having 1.4-1.5 true density. From the time of its separation in centrifugals till it is stored good amount of air gets entrapped in the molasses. This included air in the form of fine bubbles is of the order of about 15% of the volume of molasses$^1$ and is higher when molasses is handled a number of times or allowed to flow in fine stream. The viscous nature of this liquid does not allow escape of the included air.

Molasses is a very highly viscous liquid, the viscosity being higher, higher the brix. Viscosity always increases in proportion to air included and it is desirable to prevent more air getting entrapped while discharging the molasses into the tank. Viscosity value of any given sample of molasses may not be the same as the viscosity of some other molasses of the same brix since molasses viscosity is influenced by the composition of nonsugars. Raising the temperature of molasses reduces its viscosity and considerable amount of work has been done on the relationship between temperature and viscosity of molasses. In general it may be stated that for high brix molasses rise in temperature from 45°C to 50°C practically reduces the viscosity by half, but at lower temperature the viscosity reduction is much higher than this by heating for rise of temperature of 10°C$^1$. Viscosity assumes special significance in pumping of molasses from the factory to storage tanks usually located at least 100 m away from the factory, since it increases pipe friction. Hence the necessity to reheat molasses by opening steam in the pipe for easy pumping. Special rotary pumps are installed which are designed to handle higher viscous liquids.

2. Sugar mills in general produce from 3.5-4% final molasses on cane processed which has roughly the following composition—
As regards the other constituents of the molasses from Indian sugar mills producing white sugar by mostly double sulphitation process their percentages are as under—

(i) Nitrogen % 0.15—0.25
(ii) Gums % 0.5—3.5
(iii) CaO % 1.0—1.5
(iv) SO_4 % 1.2—3.5
(v) P_2O_5 % 0.25—0.3
(vi) pH 5.4—5.7
(vii) Total organic non-sugar % 15—20
(viii) Unfermentable reducing matter % 1.5—25

Wide variations are possible in the nonsugar components of molasses in as much as they owe their origin to cane juice to a large extent while some of them notably few of the organic nonsugar compounds and calcium salts are formed during the process operation. Most of the nonsugars of cane juice accumulate in the molasses, while some complex compounds are formed during heating and boiling at different stages of the process. Some nonsugars in juice undergo chemical transformation as a result of treatment of juices in clarification with chemicals like lime, SO_2, phosphates. Composition of nonsugars in juice being dependent on number of natural and other factors connected with cane cultivation, is not expected to be uniform even in one factory and thus it is natural that the molasses composition will exhibit wide variations in respect of different constituents. The above figures are only indicative in nature. In general regarding the various constituents their origin and significance following points are relevant:

(i) Ash : A very important fraction of ash is composed of potassium and calcium salts. Whereas potassium which contributes 25-30% of the carbonate ash is derived from cane juice, calcium salts are added in sulphitation method of juice clarification. Lime combines with organic acids of cane juice and also the organic acids generated due to the decomposition of reducing sugars under influence of high pH and heat, and forms soluble calcium salts. Wide variations in ash composition are reported from different countries on account of changes in cane quality occasioned by soil composition and farm practices.

(ii) Sugars : Sugars which account for more than half of the dissolved solids are mainly sucrose and reducing sugars i.e. the glucose and fructose. In process operation some
reducing sugars are formed due to decomposition of sucrose while some amount of the total reducing sugar gets destroyed. Sucrose percent dry matter i.e. true purity of molasses varies from 35 to 42 while total sugars i.e. sucrose and reducing sugars usually lie within range of 55-60% dry matter in molasses.

(iii) Unfermentable reducing matter: Out of the total reducing matter determined by Fehling’s solution nearly 10-15% is actually not reducing sugar but is a complex formed from nitrogeous compounds and reducing sugars. This unfermentable matter is not present in the original cane juice but is produced during process. Honig observed increase in unfermentable reducing matter in molasses during ten months' storage coupled with reduction in total sugar content².

(iv) Colour: Molasses owes its dark brown coloration to presence of caramel and melanoidins which are formed in the process from sugars, under action of heat and alkali. Prolonged contact of heat produces caramel from sugar while melanoidins are formed as a result of reaction between amino acids and reducing sugars.

(v) Nitrogen: Nitrogen is present in molasses in the form of amino acids like aspartic acid, glutamic acid etc. and amides. Out of the total crude protein i.e. N₂ x 6.3 nearly half is considered to be digestible portion³. Amino acids combine with reducing sugars in the process with the formation of melanoidins which are dark coloured compounds. High nitrogen content of molasses is considered one of the major causes of rapid and spontaneous decomposition of molasses which is stored at high temperatures⁴ (45°C).

(vi) Other organic compounds: Apart from amino acids and amides there are some other organic acids, which are non-nitrogenous like lactic acid, formic acid, acetic acid and aconitic acid out of which the aconitic acid forms major portion. Attempts have been made to separate aconitic acid from 'B' heavy molasses and final molasses after precipitating it as calcium aconitate by treatment of diluted molasses with calcium chloride followed by centrifuging in solid bowl centrifugal⁵.

Gums, waxes and lipids which have escaped separation in juice clarification persist till the end of crystallisation and accumulate in molasses. These contribute to the viscosity of molasses.

3. Molasses with its total sugars of 50-55% serves as an ideal raw material for fermentation and most of the molasses is thus converted into ethyl alcohol in India. Against this background proper preservation of molasses in sugar mills assumes special significance. A factory crushing around 400 thousand tonnes cane in a year produces around 14000-16000 t molasses and has to provide for storage of two thirds of the annual production, which has the potential for earning good revenue for the factory. In respect of storage of molasses, two important points need special consideration: One-any deterioration of the sugar in molasses has to be prevented, two-the danger of froth fermentation resulting in complete decomposition has to be checked.
4. In the early days of the industry molasses in many factories used to be stored in open pits dug in the soil i.e. earth pits. The dangers posed by this method such as environmental pollution due to seepage through soil and deterioration were soon realised. Later on the use of molasses for industrial purposes led to construction of concrete pits with proper roof which helped prevent dilution due to rain water and deterioration. However, the modern trend is to store molasses in cylindrical tanks of m.s. construction installed on elevated foundation. The tanks are located close to the factory but at a safe distance from spray pond and water effluent channels. The capacities of steel tank are in the range of 2000-4000 m$^3$ depending on the annual output of the factory and usually factories choose to instal two steel tanks close to each. The storage and delivery of molasses to outside agencies requires necessary equipment and piping such as inlet pipe for filling the tanks, at least two molasses pumps connected through pipes to tank as also delivery line, valves etc. The storage tanks have to be of sturdy construction and mounted on concrete or masonry foundation. The storage tank is necessarily fitted with following accessories:

(i) Inlet pipe with valve, reaching the bottom of tank.

(ii) Outlet of 15-20 cm dia from the side near the bottom connected to suction of pump through a valve.

(iii) Washout valve.

(iv) Three indicating type dial gauges for observing temperatures at different heights of the tank.

(v) Manhole of 50-60 cm opening at the top and one at the side near the bottom.

(vi) Arrangement to spray cold water all around the sides of tank to cool the contents in the event of temperature rising high.

(vii) Level indicator and ladder.

5. DETERIORATION IN STORAGE

Properly stored molasses with its 15-20% water is not susceptible to microbiological decomposition and can keep well for months together without any appreciable change of composition. Studies by Browne on the changes in composition of Cuban molasses at ambient temperature over extended periods have shown:

(i) Loss in polarisation 18.46%

(ii) Loss in sucrose 18.71%

(iii) Increase in reducing sugar 4.47%

(iv) Loss in total sugar as invert sugar 15.2%

(v) Loss in total solids 3%

(vi) Great increase in colour

(vii) Increase in organic non-sugar 13%
This slow decomposition was not attributed to any micro-biological causes in the absence of any micro-organisms like yeast moulds etc. The slow decomposition is caused by chemical reactions taking place in the molasses. Honig has shown the annual loss in fermentable sugar in storing molasses to be 2-3% at 30°-35°C while the loss of sugars was four times higher when the storage temperature is 10°C higher. Under normal conditions the molasses preheated to high temperature to facilitate pumping is likely to undergo rapid decomposition. Factories in the normal course are not required to store molasses for more than 12 months if the offtake is assured for an attached distillery.

6. SPONTANEOUS FERMENTATION

6.1. Many factories have reported rapid decomposition of molasses stored in open pits and tanks. This deterioration of molasses is accompanied by rise in temperature and decomposition of sugar as well as other organic matter ultimately resulting in charring of the entire mass. Geerligs has mentioned about such spontaneous destruction of molasses in Java. Similar instances have been reported from different cane sugar producing countries of the world. In the initial stage CO\(_2\) is liberated while the temperature of molasses rises and froth formation takes place. Although termed as froth fermentation this is not attributed to microbial action but it essentially results from chemical reactions which are exothermic and thus raise the temperature. Once initiated the reactions which are autocatalytic are very vigorous and are difficult to control.

In Indian Industry such occurrences of molasses destruction have been mentioned in literature: In one such instance in Bihar the molasses in an open pit started boiling and over flowed, the temperature noted being 100°C, even though the maximum atmospheric temperature was 33°C. Within three days the entire molasses in tank was carbonised and analysis showed zero pol %. To dissipitate the heat generated at another factory water was sprayed on boiling molasses without any effect. Similar occurrences of molasses destruction have been reported from time to time from different Indian factories and most of them have taken place in molasses stored in open tanks of masonry construction or earth pits. However even in steel tanks such type of destruction emanating from vigorous chemical reaction has taken place in some factories. Apart from loss of sugar in molasses, the mass getting carbonised and solidified on completion of reaction renders the task of removing the decomposed material from tank very difficult.

2. Experience in India and other countries indicates that this phenomenon is common to molasses from factories practising any of the defecation, sulphitation or carbonation processes of cane juice clarification.

6.2. Exact nature of the chemical reaction responsible for spontaneous decomposition is not known. According to one theory unstable organic compounds formed due to action of lime on reducing sugar in clarification react with the reducing sugars of molasses with the formation dark coloured impurities of high carbon content. The reaction of amino acids and amides with reducing sugars appears to have some role in the initial stage of the decomposition. Chen found high nitrogen content in molasses which had undergone rapid deterioration. Other workers have also suggested the formation of ‘melanoidins’
which are dark coloured products of reactions between amino acids with reducing sugars to be the cause of destructive decomposition of molasses with evolution of heat and carbon dioxide. The exothermic chemical reaction releases heat which is not dissipated in the molasses stored in tank with the result that temperature of the entire mass rises and this rise in temperature further accelerates the reaction leading to formation of froth, evolution of CO₂, and complete carbonisation of molasses.

Main contributory factors for spontaneous decomposition of molasses are high density and high temperature (45°C) of the molasses at the time of storage. Attempts have been made to suppress the froth by blowing compressed air at the bottom of molasses tank at some places with partial success or negligible effect. Use of antifoaming agents like Turkey red oil has been tried at some factories but Agarwal reports successful abatement of froth due to addition of synthetic surface active antifoaming chemicals. At some factories water spray on surface of molasses to dissipate the heat generated by the exothermic reaction has been tried without any success. Molasses with its low water content, high density and high viscosity offers very high resistance for flow in the pipelines at the time of pumping and is therefore heated by blowing live steam into the pipeline, by 5°-10°C Moreover in many factories with use of continuous centrifugal machines for purging of well boiled low purity final massecuites preheating the massecuites just before centrifuging has become essential. Under these conditions the temperature of molasses at the time of storage in tank can go up to 55° ± 5°C.

6.3. The measures suggested or tried to control the spontaneous combustion are as under—

(i) In open pits water is sprayed on the surface to control the increase in heat generated but this obviously can not check the chemical reaction in the entire mass of high density material.

(ii) Cooling of molasses prior to storage by passing it through plate type heat exchangers has been suggested but results of trial of such cooling of molasses are not available. However S.K. Bhojraj has reported successful cooling of molasses in a multipass tubular heat exchanger, with water passing through coils.

(iii) Control of froth generated which leads to over flow of tank is claimed to have been achieved by SKD Agarwal with addition of antifoam agent and recirculation of molasses in the tank.

(iv) Blowing compressed air into the mass of stored molasses is found by Trivett to dissipate heat generated and check the development of further reaction.

(v) Recirculating the molasses by pump so as to replace the upper most layers of the mass with the molasses at the bottom. This serves to check to some extent the autocatalytic chemical reaction.

Despite the considerable researches carried out in the past 6-7 decades into the exact causes of the catalytic nature of the chemical reactions responsible for spontaneous combustion of molasses, the problem has eluded solution. Out of the measures outlined above no single measures has been found effective in checking the decomposition reaction, under all conditions of storage and it is therefore prudent to adopt preventive
measures for avoiding conditions conducive for above or other exothermic reactions to set in. As stated earlier the molasses stored in hot condition at temperature exceeding 45°C is prone to spontaneous combustion and best way is to store molasses at temperature lower than 42-45°C. According to Fromen & Bouland safe limit for storing molasses is 40°-43°C.

It is thus desirable to use minimum low pressure steam (about 1 kg/cm²) at the time of pumping. In summer months in areas with day temperature reaching 40°C and above, when hot molasses is pumped into storage tank it is advisable to recirculate the molasses in the tank so as to bring down the temperature and prevent heating of the mass. Beside, following precautions need to be taken to avoid this decomposition of stored molasses.

(i) Vacuum of the pan during boiling of final massecuite has to be high i.e. 635-650 mm so as to maintain low temperature of final massecuite boiling. In Beet sugar industry froth fermentation has been reported in final massecuite strikes when pan boiling temperatures were high.

(ii) Careful watch is required on the quality of cane with regard to nitrogen content as the accumulated experience over the years shows that molasses containing higher nitrogen then normal molasses is susceptible to rapid deterioration. Chen has observed froth fermentation even in 'A' heavy and 'B' heavy molasses tanks and high reddish colouration. According to him nitrogen content of molasses should be used as an indicator for preventive purposes.

Molasses from cane which has deteriorated in the field due to borer or other pest infestation is reported to contain higher nitrogen than that from normal cane and while procuring such cane, extra precautions are required in respect of a heating of molasses and it is advisable to either dispose of such molasses without delay or store it separately to protect the major stock of molasses of normal characteristics and thereby to save the remaining stock of molasses from rapid deterioration.

(iii) In case the temperature of stored molasses in any tank is found rising it is desirable to recirculate the same and if foam formation is noticed foam subsiding agents should be added to the molasses. Since foam formation results from liberation of gases-particularly CO₂ supressing it would prevent overflow of molasses from tank.

(iv) It is better to have at least 2-3 storage tanks of molasses preferably of steel construction instead of one storage tank.

(v) The storage tanks whenever emptied should be washed thoroughly with water.

(vi) Temperatures of molasses in the storage tanks should be noted as a matter of routine once every 4-6 hrs to facilitate checking the trend in the rise in molasses temperature well in time.

(vii) Analyses of stored molasses have to be carried out regularly for the sugars, ash and nitrogen contents.

(viii) During hot weather particularly, the molasses in the steel tanks can be cooled by recirculating the same and running cold water spray around the exterior of the tank.
REFERENCES

5. c.f. Ibid p. 374.
7. ibid p. 365.
14. Ibid.
13. VACUUM SYSTEMS

1. The juice concentration in evaporator and crystallisation in pans are carried out under vacuum and for producing vacuum, special equipment has to be installed in sugar mills. In its simple form the equipment consists of:

(a) condenser connected to the vessel in which boiling under vacuum is taking place, through a large vapour pipe and

(b) air extraction arrangement.

Cold water is continuously pumped into the condenser, which condenses the vapour and gets heated. The hot water from the condensers has to be reused for which special cooling system is installed involving atmospheric cooling by spray in ponds or surface cooling in towers. In old plants the practice was to install one central condenser for all vacuum pans and one condenser for evaporator station. A large size injection water pump used to cater to the needs of all the condensers while the air extraction was effected by means of a large air pump or vacuum pump, suitably communicating with the condensers. In modern plants however, each boiling pan is connected to a separate condenser and air extraction equipment. This arrangement eliminates the risk of fluctuations in vacuum caused by starting of each pan and the possibility of entrainment arising therefrom in the system involving one central condenser for all pans.

2. In a condenser the vapours entering, transfer heat to the cold injection water, the heat transmission depending on the temperature and quantity of water. Based on the heat balance the equation for arriving at the quantity of injection water is:

\[ W = \frac{(I-t_2)}{(t_2 - t_1)} \]

where \( W \) = Kg of injection water per Kg of vapour

\( I \) = heat of vapour in Kcal/kg

\( t_1 \) = temperature of injection water in °C

\( t_2 \) = temperature of condenser outlet water in °C. Under normal conditions the cooling water ratio to vapour condensed in around 50.

The quantity of water will be governed mostly by the difference in \( t_1 \) and \( t_2 \) since in a factory vacuum is maintained at 635 - 650 mm with minor variations. According to Hugot the optimum value of this difference is 10°C.

The difference in temperatures of vapour being condensed and the—outlet water termed as approach should be minimum since the efficiency of the condenser operation depends on the fact that minimum quantity of water should absorb all the latent heat of vapour.
3. AIR AND INCONDENSIBLE GASES

3.1. Air and incondensible gases entering the condenser have to be removed for proper functioning of the vacuum system. These gases referred to as air owe their origin to:

(a) air leaks in vessels, pipes etc.
(b) incondensible gases released on juice concentration.
(c) air contained in injection water fed to condenser.

3.2. Air leaks—The magnitude of air leaks is difficult to ascertain in a vessel and in particular where the maintenance of equipment is of a high order the leakages won't be substantial. These leaks take place through various joints, valves, sight glasses in vessels and vapour pipes.

A test is described by Perk in which the fall in vacuum in a vessel is determined after shutting off the condenser and air pump. According to him a rise in pressure not exceeding 67 mbar in five minutes indicates satisfactory air tightness. The following table according to Perk\(^2\) gives the quantity of air leak in a vessel under vacuum:

<table>
<thead>
<tr>
<th>Time required for pressure rise of 50 mbar in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>12.5</td>
</tr>
</tbody>
</table>

According to Perk, for vessels as under

<table>
<thead>
<tr>
<th>Air leakage Kg/hr into vessel of 30m(^3) under vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.2</td>
</tr>
<tr>
<td>10.6</td>
</tr>
<tr>
<td>8.5</td>
</tr>
</tbody>
</table>

3.3. Incondensible gases—According to Hugot the incondensible gas required to be evacuated is 200-250 p.p.m. by weight of juice to be evaporated in an evaporator and 50-100 p.p.m. per tonne of syrup introduced in vacuum pan\(^4\).

3.4. Air in injection water—Cold injection water under atmospheric pressure contains air which is evacuated in the vacuum system. The quantum of air by weight in relation to injection water in factories with cooling tower or pond is 30-40 p.p.m.

3.5. Taking all the above factors into account the air to be evacuated is reckoned by Perk, for vessels as under\(^5\)
4. CONDENSER

4.1. Condenser is a cylindrical closed vessel with a long pipe attached to the bottom open at the lower end. The cylindrical body of the condenser is usually constructed of M.S. plates but the conical bottom and throat of the condenser as well as tail pipe should preferably be made of C.I. The condenser is a vessel with a barometric column extended into a well with water seal and is therefore installed on a special platform at a height of 11 m. above the well so as to maintain water coloumn of 10 m. since the injection water has to flow by-gravity from the condenser and the water column corresponding the perfect vacuum of 760 mm is 0.76 x 13.6 = 10.34 m. the density of mercury being 13.6.

The condenser vessel has connections for;

(a) vapour inlet from vapour pipe
(b) injection water inlet
(c) air extraction, the last one being eliminated in multijet condensers.

The height of condenser and the baffles installed inside the condenser determine the time of contact of vapour with water and it is extremely important that thorough contact is established between the vapour to be condensed and the cold injection water for bringing about proper heat exchange between the hot vapour and cold water fed to condenser. The baffles provided inside the body of condenser serve to divide the cold water into a number of small streams of water which provide greater area of contact. At the same time the baffle arrangement should in no way obstruct the passage of vapour. The height of normal counter current condenser from top of water column to injection water inlet provided with 4-6 baffles is around 3 m.

The volume of condenser vessel for rain type condenser is 0.5 $m^3$ per 1000 kg vapour and for other types 0.62 $m^3$ per 1000 kg vapour according to recommendations of Queensland Sugar Experiments station.6

4.2. Types of condenser—

4.2.1. Two major types of condensers are:

(i) Condenser with separate arrangement for air extraction
(ii) condenser with combined vapour and air extraction.

In the first type are—

(a) co-current condenser wherein the water and air flow are in the same direction.
(b) Counter current condenser in which air circulation is in opposite direction to water flow. Multijet condenser belongs to the class of cocurrent condensers which remove both vapours and air.

4.2.2. In co-current or parallel flow condenser the vapour entry is usually from top and water connection provided in the upper portion of the condenser vessel while the air extraction outlet pipe is fitted in the space between the top of tail pipe and water inlet in the lower portion of the condenser barrel.

4.2.3. In a counter current condenser vapour entry is arranged at the lower portion of condenser while the water inlet and air withdrawal are provided at the top of the vessel and thus vapour and injection water enter at opposite ends. As the air leaves the condenser near the cold water inlet it gets cooled to very near the temperature of injection water and is then separately extracted either by vacuum pump or separate air extracting condenser. In order to bring about intimate contact of vapour with water it is essential to divide cold water into fine stream for exposing more surface to vapour. This is accomplished in different ways as follows—

(i) Incoming water is made to cascade over weirs and circular trays arranged alternately so that water falls in curtains.

(ii) Injection water is sprayed through a number of nozzles spaced evenly along the periphery of the top of condenser.

(iii) In rain and shower type condenser the water passes through perforated trays and is divided into shower type streams. A few baffles are also provided to facilitate upward flow of air.

Various arrangements of baffles are aimed at dividing the charged cold water into fine streams or curtains so as to provide intimate contact of vapour with large surface of water. In a counter current condenser the air gets cooled by the cooling water whereas in condenser with parallel current system air leaves at almost the same temperature as the warm water. In a well designed counter current condenser under optimum conditions the approach should be 3°C and the air leaves at the temperature of 5.5°C below that of injection water.  

When air is removed by vacuum pump it is essential to avoid the traces of water reaching the air pump which would suffer damage and a water separator is installed between the condenser air outlet and air pump.

4.2.4. Multijet condenser—This type of condenser which performs the twofold function of condensing the vapour and air extraction is installed in many factories in India. In multijet condenser near the top a part of water is sprayed through nozzles which receive water through annular jacket and the remaining water passes through another branch and is sprayed into jets through nozzles into the throat of the condenser. Thus the main injection water line near the condenser has two branches one for top spray which condenses vapour and the other lower branch for jet spray which accomplishes air extraction. The water pressure at jets is around 0.4 kg/cm². This type of condenser requires good amount of water and the system consumes lot of power. But the main
advantage is the less machinery maintenance in this type as compared to a combination of vapour condenser together with air pump. In the multijet condenser, which is a cocurrent or parallel current condenser, the injection water is supplied for both vapour condensation and air extraction from the same pump and the entire system consumes more power as compared to other condensing systems. In view of the urgent need to reduce power consumption of condensing system which accounts for nearly 30% of the total power load in a factory with multijet condensing system, modifications in the condensing system have been brought about and implemented with satisfactory results. The system modifications are as under:

1. In a multijet condenser almost half the power is required for air removing jets and if air extractor is installed separately outside the condenser, at lower heights, the water discharged can be reused without further cooling. Thus condensation of vapour takes place inside the existing condenser but the overall power consumption is brought down due to reduction in load on
   - spray system and the
   - injection water pump.

2. Most effective way is to have a counter current rain and shower type condenser with external air extractor at lower heights with circulation of discharged water from the same unit. This will result in power reduction by 30-40% over that for multijet condenser which receives water from one injection water pump for both vapour condensing nozzles and air ejector nozzles.

5. AIR EXTRACTION

5.1. For air extraction outside the condenser body special equipment installed can be broadly classified into three types:

   (a) Air pumps - reciprocating type

   (b) Air pumps - rotary type

   (c) Water jet air ejectors

   (a) Reciprocating type vacuum pumps driven by electric motors and running at 1100-1200 r.p.m. suck air from the condenser and deliver it to atmosphere. These are however, being rapidly replaced by rotary liquid annulus pumps on account of their high maintenance costs.

   (b) Liquid ring rotary pump—In this pump a shaft with radial vanes attached, is located in an eccentric position in a drumlike pump housing. The drive for pump is provided by electric motor either by direct coupling or through V belt. The gap between the ends of rotor vanes is maximum at the suction side and minimum at the discharge opening. Water seal helps to maintain the housing cool and part of water is discharged with air, which can be recirculated. These pumps are energy efficient as they consume less power and water in comparison to water jet extractor and besides
5.2. Steam jet air ejector—In this type of air ejector steam at 5-7 Kg/cm² pressure is admitted at the top which entrains the air through the opening provided on the side of the ejector. The steam enters through a nozzle and extracts air by friction. The steam may be slightly superheated though actually dry saturated steam is required. Its application should be limited to units where vacuum boosting is essential or for priming on account of the high energy consumption of the unit.

5.3. Water jet air extractor—In this jet type condenser water jet aspirates the air and this can be used in combination with counter current barometric vapour condenser. It is located at about 4 m height above the top of waterwell and as the water leaving the condenser is practically at the same temperature as the water fed to jet, the discharged water can be pumped back to jet and the delivery head of pump required is much less than in vapour condenser.

An interesting system involving use of air jet ejector adopted in Java has been described by Perk. The air ejector operating with water at pressure of 1-1.5 kg/cm² is bolted to a barometric condenser. The tail pipe water of air ejector is delivered into a tank located about 4.2 m below the condenser. This water from air ejector is sucked in the barometric condenser due to higher vacuum of 635-650 mm and no separate injection water pump is required for barometric condenser which discharges its water in the usual way through its tail pipe. Thus the water is used twice: for air extraction and vapour condensation.

6. COOLING SYSTEMS

6.1. In white sugar factories the total water requirement for vacuum system is of the order of 30 m³ per tch. Thus a factory handling 100 t cane per hour will require 3000 m³ of cold water per hour. In some factories blessed with ample supply of cold water from nearby stream or river, the waste water from condenser is let into stream and replaced by fresh cold water. However, in most of the plants in the absence of this facility the common practice is to cool the warm water in special cooling system for reuse. These systems operate on the principle of providing as great exposure of warm water as possible to the atmosphere, and can be broadly divided into two types

(a) spray pond

(b) cooling tower.

(a) Spray pond is constructed by digging a large pit where water is cooled by spray through a number of nozzles located at regular intervals. The warm water from the factory condensers flows into a pit adjacent to the spray pond from which water is pumped to spray nozzles through cluster of pipes. Spray nozzles are so spaced as to prevent the cloud formed from one set of nozzles interfering with the spray cloud from another one. The water emerges in the form of cloud of droplets rising nearly 1.5 to 2 m above the base of the nozzle pipe and comes into contact with surrounding
air, a small part of it evaporating. This intimate contact with air and evaporation bring about the cooling of water.

(b) Cooling tower: Yet another way of cooling waste water is to pass it through towers over trays, meeting upward current of air from a fan. Unlike the spray pond it occupies less space.

6.2. Theoretical: Since evaporation is a dominant factor in functioning of the cooling system, the air coming into contact with water will absorb the water vapour until it gets saturated as indicated by the wet bulb temperature. The lowest temperature to which the warm condenser water is cooled is the wet bulb temperature and the efficiency of cooling system is given by

\[ Ec = \frac{t_1 - t_2}{t_1 - t_w} \]

Where \( Ec \) = efficiency

\( t_1 \) = temperature of warm water entering cooling system.

\( t_2 \) = temperature of cooled water leaving the system.

\( t_w \) = wet bulb temperature.

7. SPRAY POND

7.1. The warm water from evaporator and pan condensers is led through a channel to spray pond and the cooled water from spray pond in conveyed through another channel to the factory where injection water pumps are installed. The two channels as also the spray ponds are of masonary construction and the water flow is always by gravity. The spray pond is usually located about 50-100 m away from the main factory building. The spray pond bottom, side walls as also the water channels have to be properly constructed and leakproof and in respect of its construction and size following points need special attention.

(i) The depth of water in the spray pond should be one meter and maintaining greater volume of water presents no advantage as it is the surface exposed to atmosphere which is useful from the point of view of cooling.

(ii) The area of spray pond should be based on the quantity of water to be cooled taking the figure of 751 Kg. of hot water per m\(^2\) area per hour as recommended by different authorities.

(iii) The distance between nozzle clusters has to be 3-4 m and the nozzles on each pipe should be spaced with distance of 2-2.5 m.

(iv) The clear space between the walls of the pond and peripheral nozzles should be 3 to 4 m on the windward side and 6-8 m on the leeward side.

(v) The pressure of the nozzle is usually 0.5-0.6 kg/cm\(^2\).

(vi) Nozzles of different type are used, the principle amongst them being
(a) involute type.

(b) conical jet, and trials in Queensland with different types have shown the conical jet type to be most effective.

The nozzles are fitted to pipes resting over pillars in the pond in clusters of five. The pipes are progressively diminishing in diameter from the pump end.

7.2. Mist creation system—In a recent development in India a new more efficient spray cooling system was established in which the pressure at the nozzles is 2.5 kg/cm\(^2\) and mist is created at the spray. The pipes and nozzles of the spray head are made of synthetic resin PVC with very low frictional resistance. The spray pumps installed develop head of 25 m and mistlike water spray rises to a height of 3-4 m ensuring intimate contact with air and dissipation of heat. Satisfactory working results have been reported with this system which can be adapted to the existing spray ponds with some modifications in spray ponds and spray pump. Yet another advantage reported by users of mist creation system is the reduction in B.O.D. value of spray pond water on account of thorough contact of air with water.

8. COOLING TOWERS

This is a compact cooling system occupying much less space and gives better cooling results than the spray pond but consumes more power than the latter. The entire equipment consists of cooling tower with fans and pumps for warm water which is delivered to the top of the tower. Water flows down the series of trays fitted with slats and louvres, and meets rising currents of air generated by high capacity fan installed at the bottom, for forcing air upwards. The approach achieved is very low but the maintenance costs are higher than with spray system and the size of the towers has to be selected taking into account maximum heat load, dew point and approach aimed. In cane sugar plants at the time of expansion of capacities and also where space availability is limited it may be desirable to install cooling towers. But by and large from the point of view of ease of maintenance and energy consumption spray ponds are always preferred.

9. MISCELLANEOUS

Unless space is a constraint, spray pond which is of masonry construction should be adequately sized keeping in view future plant expansion prospects. The spray piping is made of C.I. but the nozzles in the conventional spray ponds are of bronze construction while the pumps deliver the water at 10 m head. It would however be advantageous to develop higher pressures at spray upto 1-2.0 kg/cm\(^2\).
REFERENCES

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14. STEAM CONSUMPTION AND STEAM ECONOMY MEASURES

PART I

1. Importance of steam economy in cane sugar industry has been recognised since decades and attempts at modernisation of old plants or planning of new sugar projects necessarily deal with measures for energy conservation, and steam economy. It needs to be emphasised that out of the total energy consumed in cane sugar manufacture major portion nearly 90% is accounted for by the steam consumption of the process house, while small percentage of it is required for generating electric power. Compared to raw sugar production, white sugar manufacture from cane involves higher steam consumption by 5-10% and in recent times drive for improvement of sugar quality necessitated increased melting of sugar from low grade massecuites coupled with boiling of high purity massecuites from which white sugar is produced, resulting in higher steam load in process. Economy in steam consumption in process is directly related to saving of bagasse which can serve as valuable raw material for the manufacture of paper, furfural etc. or for producing additional power for other industries.

2. STEAM CONSUMPTION

A sugar factory operating with optimum capacity utilisation, producing good quality sugar will consume about 60% steam on sugarcane processed in the absence of vapour bleeding arrangement from evaporator. The stationwise steam requirement are presented in Table I. The table also presents picture regarding the energy requirements in terms of heat units for major operations in the plant and shows that the boiling house operations account for nearly 90% of the total heat energy consumed in the entire factory working and consequently it is imperative to lay maximum emphasis on economising the steam consumption in the process operation. The design of modern sugar plant for maximum steam economy is based on two main principles.

(i) Maximum use of vapours from different bodies of evaporator for juice heating and pan boiling.

(ii) Low production of exhaust steam in prime movers.

As is well known the vapours from all evaporator bodies can be used for juice heating while the entire pan boiling can be carried out by employing vapours from pre-evaporator and first body of the evaporator.
In the plant design if the targeted steam consumption of sugar plant is 40-45% cane or lower it is essential that the exhaust steam production does not exceed 30-35% cane which calls for installing high pressure boilers operating at 31 to 41 kg/cm$^2$ together with the prime movers to suit the high pressure and high temperatures (390° - 400°C) of steam. As the entire exhaust steam produced by prime movers is consumed in the boiling house the steam economy measures have to be within the safe limits of exhaust steam generation to avoid exhaust blowing out into atmosphere.

3. CAUSES FOR HIGH STEAM CONSUMPTION

3.1. The factors responsible for high steam consumption in sugar mill can be investigated from two angles viz.

(a) plant design

(b) operational problems.

3.2.1. Design aspects—A sugar plant has to be properly balanced with respect to capacities and heating surfaces provided at different stations and any imbalance in capacities at evaporator or pans proves too expensive from the energy consumption point of view. More heating surfaces in operations than called for by the plant capacity requirement, result in higher steam consumption than normal. Similarly inadequate capacity at any station not corresponding to the crushing rate for which the plant is designed also has similar deleterious influence on steam consumption. Yet another point of great significance is the capacity of the sugar mill and it is now acknowledged that the larger capacities favour incorporation of all the above steam economy measures particularly the elaborate vapour bleeding designs, large capacity pans and high pressure systems for boilers and prime movers. Plant capacities of minimum 2500 t cd are more suited to these systems and below the capacities of 2500 tcd, the plant designs do not lend themselves well for high pressure boilers or larger boiling units.

As regards the special features which need to be incorporated in systems design of the plant, elaborate vapour bleeding from different vessels of evaporator assumes special significance. Out of the vapour bleeding systems the one that is effective in bringing about steam economy without exerting harmful influence on the sugars and composition of syrup needs to be considered by technologists.

3.2.2. Vapour bleeding—As stated earlier withdrawal of vapour from different bodies of quadruple or quintuple coupled to preevaporator constitutes the most important technique of reducing steam load, the most favoured systems being—

(i) Preevaporator which furnishes vapours to pans, joined to a quadruple with vapours being drawn for juice heating from first to last body.

(ii) Pre-evaporator generating vapours for pans and a quintuple effect evaporator which supplies vapours from first three bodies for juice heating.

In the above systems of vapour bleeding the juice heating is accomplished as follows—
(i) Raw juice is heated by vapours from last body of quadruple up to 43°-44°C and further heated to 70° - 75°C by vapour drawn from 2nd body, or alternatively. Raw juice is heated to the desired temperature by 3rd body vapours or 2nd body vapours.

(ii) Treated juice heating up to 90° - 92°C is carried out by vapours from first body while further heating to 102°C is completed by using vapours from vapour cell or exhaust steam the former being preferable.

Planning for vapour utilisation must be accompanied by providing adequate heating surfaces of different vessels of evaporator.

In the case of juice heaters these have to be operated in series, when raw juice or treated juice heating is effected by employing vapours from two different bodies or by using vapour and steam.

3.3.1. Operational aspects—In a well balanced plant, despite all the steam economy arrangement steam consumption can go out of control if the factory is not crushing to its rated capacity. Every factory has to work out its own optimum crushing rate below which the steam economy measures as envisaged in the plant design become ineffective resulting in higher steam consumption than expected in the context of a particular plant design and it is essential for every sugar mill to maintain a certain minimum grinding rate. This calls for uninterrupted cane supply to the factory and minimum mill stoppages. A sugar mill must maintain a grinding rate of about 10% to 20% higher than the rated plant capacity to take care of minimum crushing rate, minor mill stoppages, variation of cane quality etc. Moreover higher crushing rates than the designed capacity always result in energy saving.

3.3.2. The stoppages in operation can be attributed to

(a) irregular cane supply
(b) machinery breakdowns or
(c) process difficulties, but the problems on account of these factors can be tackled by proper management of cane requirement, preventive maintenance of machinery and effective process control respectively. Even short duration stoppages disturb process working at juice heater and evaporator but longer stoppages affect the working of all stations including boilers. A smooth running plant operating at optimum crushing rate can achieve substantial steam economy in process by utilising 90% time for crushing i.e. with stoppages of 10% or below, of the available hours.

In the event of prolonged stoppages either on account of interruption in cane supply or machinery breakdown the boiling house operation should be stopped within an hour of mill stoppage to avoid wastage of steam. On the days of periodical shutdown for cleaning of heating surfaces, care has to be taken to complete the cleaning and maintenance job within 16-20 hrs. for which thorough planning of the various activities involved, is essential. Generally it is practicable to stop the process operation and even the main power turbine on the cleaning days within 10 hours of mill stoppage.
3.3.3. It is the usual experience that perfect co-ordination between the Engineering section and process operation staff is of vital importance in the drive for steam economy. As for instance exhaust blowing out into atmosphere resulting from the steam consumption not keeping pace with exhaust production mostly is avoidable by co-ordination of the working of exhaust generating prime movers and pans.

4. STATIONWISE MEASURES FOR STEAM ECONOMY—

4.1. Mills—In keepings with the present trend of employing higher inhibition at mills—above 200-250% fibre which helps improve extraction of sugar at this station the factories have to add more water at the mill, which many times creates difficulties in the mills gripping the wet bagasse when the water is at high temperature. This situation is tackled in many factories by use of low temperature water obtained by admixture of cold raw water with hot condensate. This however is undesirable and high temperature condensate only should be used without resorting to cold water mixing. The problems created by wet bagasse and hot water can be effectively solved by adopting proven techniques like arcing of rollers or providing pressure feeding devices or new types of lotus rolls.

4.2. Clarification—Hot condensates only should be used in preparation of lime and phosphate solutions added in juice clarification.

The entire juice heating can be carried out by vapours from evaporator as stated earlier and it is essential to provide adequate capacity at this station to enable—

(a) series heating in two heaters with different temperature vapours

(b) maintaining heating surfaces clean by descaling during running at regular intervals

(c) frequent changing of heaters for raw and treated juices.

4.3. Evaporater—The primary function of multiple effect evaporater is to remove 70-75% of water from the juice in the most economical way and maintaining brix of outgoing syrup at 60° - 65°C has a great bearing on the process steam consumption. As far as possible brix controller or at least recorder should be installed for syrup. Automatic controls for juice levels in bodies are helpful for consistent results in evaporater.

In order to reduce the scale deposition on heating surface scale inhibiting chemicals which have been introduced in recent years can be used with advantage. The interval between two cleanings or the frequency of periodical shutdown for cleaning, should be determined taking into account need to maintain minimum rate of evaporation in each body for maintaining the desired concentration of juice to syrup as also for furnishing adequate vapours for pans and juice heaters.

Evaporater must always receive regulated feed of clear juice and exhaust steam at constant pressure for which provision of—

(a) overflow valve

(b) automatic pressure regulation is essential.

The degree of superheat of exhaust should not exceed 15°C - 20°C.
4.4. Pans—Because of the batch operations and the important role of the human element in the boiling operations the pan station influences the steam consumption to a considerable extent. Various steps which contribute to control of steam requirement at crystallisation station are given in brief below—

(a) Brixes of each strike have to be as high as the equipment permits, as lower brixes of 'A' and 'B' strikes increase the total massecuites to be boiled while high brixes increase recoverable sugar from each strike and reduce the quantum of boiling.

(b) Recirculation of sugars and nonsugar which inevitably takes place in pan boiling in the white sugar manufacture needs to be controlled to avoid unnecessary massecuite boiling and it can be properly managed by producing even sized grains, tight boiling accompanied by efficient centrifugal separation which would lead to recovery of maximum of sugar per unit of massecuite boiled of each grade.

(c) Water used for molasses conditioning has to be restricted to dilute molasses to 70° - 72°C Bx. and it is desirable to instal molasses conditioners with automatic temperature control to avoid overheating of molasses. The old method of heating molasses in storage tanks being wasteful is being discarded in favour of separate conditioning equipment in modern plants.

(d) Water used in pans as movement water should be metered for exercising control on the unnecessary use of water in pans. Recording the amount of water for boiling has been found to be useful in controlling steam consumption in pans.¹

(e) For pan washing exhaust steam can be effectively used as described earlier in preference to live steam. Having a small number of pans of high capacity is always advantageous as compared to a large number of pans of smaller capacity found in factories which undergo expansion of plant capacity as it brings down pan washings. Continuous pans are ideal from this point as in their operations no dropping of strikes followed by washing is encountered.

4.5. Centrifugals—At centrifugals use of water is confined to washing sugar in centrifugals, melting of washed sugar from B and lower grade massecuites and sometimes even for magma making in the mixer. In the purging of 'A' massecuites from which white sugar is produced either the steam of about 5 Kg/cm² pressure is employed for removing free water from sugar in the basket or superheated wash water at about 125°C is used. Since in the centrifugal separation, with the exception of final products of manufacture viz. sugar and molasses, all intermediate sugars and molasses are sent back to pan floor, the control on quantity of water for various functions has a great bearing on the steam load on the pan station and in this context special steps are essential in the control of use of water as stated below—

(a) Water used as sugar wash in machines should be minimum and carefully determined.

(b) Separation of light and heavy molasses in case of single curing of massecuites has to be efficient to reduce load on boiling.
(c) For melting of sugars from low grade massecuite clear juice can be used but the melt has to be sent to syrup sulphiter. But in case the melt is to be stored separately hot condensate has to be used with proper control on brix of melt.

(d) For preparing magma of sugar from any massecuite light molasses from the same massecuite purging should be invariable used.

5. ENERGY CONSERVATION MEASURES

5.1. Conservation of hot condensates—Sugarcane contains nearly 67-70% water out of which nearly 15-19% cane is available for process operation, the remaining being accounted for as under—

(i) Bagasse 13-15 % cane
(ii) filtercake 2.5-2.8 %
(iii) Molasses and sugar 0.6-0.9% and
(iv) Vapours going to condenser from evaporator and pans 32-36% cane.

The condensates from process operation at juice heaters, evaporator and pans apart from being practically free from impurities have a temperature range of 70° - 95°C and thus find wide use at all stages, from juice extraction to centrifugals. In the process operation major consumption of hot condensates take place at—

(a) mills,
(b) clarification, for lime and phosphate preparation,
(c) pans,
(d) centrifugals, besides boilers to make up for the shortfall in boiler feed water.

In fact the available condensates more than meet the process demand and can be preserved for emergency. Many times on account of uneven draw of condensates at some station or during mill stoppages, shortage of condensate is experienced which necessitates use of cold water. This is avoidable as it means waste of steam. Proper management of condensate involves—

(a) adequate storage of condensates
(b) no wastage due to overflow,
(c) storage of surplus condensates in separate tank,
(d) preventing leaks of condensates through pipes or pumps to gutters.

Needless to state that for conserving energy the pipes and storage tanks have to be properly lagged. Special mention has to be made of the need to collect overflow of different condensate receiving vessels, into a separate tank of adequate capacity which can be used particularly for boiler feed in the event of mill stoppages. All tanks for hot condensates must be closed units as in tanks with open tops the heat loss due to evaporation at the surface is substantial.
5.2. Insulation—Insulation of hot surfaces of piping and various bodies containing process materials, with the object of preventing loss of heat through radiation and convection is universally practised. As temperatures of hot surfaces rise, radiation loss increases since the amount of heat loss by radiation is proportional to the fourth power of absolute temperature. At 200°F (93.3°C) and 300°F (148.9°C) the radiation loss is estimated to be 1.9 and 3.4 times that at 100°F (37.8°C).\(^2\) At higher temperatures convection loss also increases rapidly thus adding to the total heat loss. Moreover, higher air movement in the surroundings further contributes to heat loss from heating surfaces. The extent of heat loss to surroundings is given by various authors as under—

(i) In a quadruple with insulated surfaces the loss of heat is equivalent to 2.7% steam supplied to evaporator.

(ii) For bare flat surface of say tanks the loss of heat is 295 BTh u./sq ft/hr, when the internal temperature is 200°F or 93.3°C. (800 K cal/m\(^2\)/hr.)\(^4\)

(iii) In the case of untagged bare pipes conveying steam the approximate heat losses per unit area exposed to atmosphere at 70°F or 21.1°C for three ranges of temperature inside the pipes are as under.\(^5\) (BTh u./sq. ft./hr or KCal/m\(^2\)/hr.)

<table>
<thead>
<tr>
<th>Pipe Diameter (in)</th>
<th>Internal Temperature (°F)</th>
<th>Heat Loss (BTh u./hr)</th>
<th>KCal/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>600°F (315.6°C)</td>
<td>2671</td>
<td>7243</td>
</tr>
<tr>
<td>6</td>
<td>500°F (260°C)</td>
<td>1810</td>
<td>4906.5</td>
</tr>
<tr>
<td>6</td>
<td>250°F (121.1°C)</td>
<td>454</td>
<td>1231.3</td>
</tr>
</tbody>
</table>

Quite often though the steam pipes or hot juice pipes are lagged the pipe flanges are bare and substantial loss of heat is occasioned from bare flanges. This can be avoided by proper insulation of the flanges along with the lagging of pipes.

6. PHYSICAL LOSS OF STEAM

6.1. In sugar plant loss of steam to atmosphere can be caused by two factors—

(i) leaks,

(ii) steam blow out, Leakages in steam or hot water pipes can result in considerable loss of heat since a small leak of 1/8" dia (3.175 mm) in a pipe conveying steam at 100 lbs pressure (7.0 Kg/cm\(^2\)) will result in loss of 56 lbs (25.4 Kg) of steam. The leaks in steam and hot water pipes need to be attended to expeditiously in the light of such heavy loss.

6.2. Exhaust blow out—The exhaust generated by the prime movers in a sugar plant is entirely used for process operation and in modern plants, with introduction of high pressure boilers and prime movers designed for high pressure steam, the exhaust production falls short of the consumption by about 15-20%. Thus in normal operation the exhaust steam should not be blown out of relief valves, but occasionally on account of some imbalance
caused in process operation at pans, the exhaust steam is not consumed but blown out. The disturbance in exhaust consumption is mostly attributable to peaks and valleys in steam demand at pan station whenever some pans are dropped or started at about the same time. This situation can be avoided by proper regulation of pan operation so as to maintain steady evaporation at that station.

6.3. The incondensible gases are vented out from the steam and vapour chests of evaporator bodies, pans and juice heaters to ensure efficient heat transfer and in most cases the gas valves are manually operated. Controlling the openings of these vent valves, so as to avoid loss of vapour or steam while eliminating the incondensibles is important for efficient operation and is closely linked with proper training of operative. At the evaporator station, for efficient venting, temperature gauges should be fitted in the vapour chest and the incondensible gas line and the gas valve regulated to maintain temperature difference of 1.50 - 2°C.

6.4. Steam traps installed at various stations, where steam is employed for heating or boiling, for isolating condensed steam from steam, have to be functioning well. Much, however depends on the maintenance and correct choice of the design of traps to suit a particular set of conditions of operation. It is desirable to provide strainer and by pass for each trap.

7. MISCELLANEOUS

7.1. Desuperheating—The exhaust steam from prime movers is usually at a higher temperature than corresponds to its saturation temperature and as it falls short of the process requirements, arrangements are provided for bleeding live steam at 5 kg/cm² in the exhaust. As superheated steam has poor heat transfer properties desuperheating of exhaust steam is effected in a separate unit known as desuperheater, wherein with addition of water the temperature of steam is brought down. With manual operation of this valve, the regulation of steam temperature is unreliable as many times the temperature on the exhaust line can be higher by nearly 50°C above the saturation temperature. Now a days automatic control system which regulates the water valve operation on the basis of temperature at the outlet has proved to be beneficial and it is absolutely essential to instal thermostatic control for desuperheating unit.

7.2. Instrumentation—Proper use of instruments for measuring temperature, pressure and quantities is of great assistance in exercising rigid control over steam consumption at different stations. Apart from the steam flow-meters at boilers the following gauges and meters must be provided at various stations—

(i) Temperature and vacuum gauges at juice heaters, evaporator bodies, pans, centrifugals.

(ii) Water flow meters for boilers and pans.

(iii) Flow meters for exhaust steam and live steam of reduced pressure.

(iv) Temperature indicator for exhaust steam.

(v) Meters for measurement of water used at centrifugals.
(vi) Brix indicating meter for syrup at evaporator.

It is desirable to maintain proper records of the readings of temperatures and pressures at all stations.

7.3. Consumption of condensates—The importance of conserving the heat in condensates and making the best use of it in process operation cannot be overstressed.

8. RECENT TRENDS

In recent years in order to achieve high steam economy in the process, special measures have been adopted which have been found to be beneficial. Some of these have been described below—

(*) Use of boiler blow down heat—In order to maintain specified levels of dissolved solids in the boiler water, frequent blow down of the water, rich in accumulated sludge composed of salts and other impurities, is practised and this represents an unavoidable loss of heat energy. In order to minimise this loss continuous blowdown based on the dissolved solid content of boiler water is essential. The blowdown water representing around 2-3% feed water is at the same temperature as the saturation temperature of steam in the boiler and obviously higher the boiler pressure, higher will be the heat loss in blow down. The heat in this high pressure water which is flashed into atmosphere can be recovered by connecting the blowdown system to the low pressure system of the boiling house for being used in heating and boiling of juices. For example we consider two sets of boiler conditions with 2% blowdown connected to vapour pipe through suitable flash vessels to generate vapours with 0 Kg/cm² pressure. The steam generation is 50 t/hr and blowdown quantity one tonne/hr.

(a) Pressure 21 Kg/cm², total sensible heat in boiler blowdown = 221.2 K Cal/Kg.

- Heat at 0 Kg/cm² = 100 Cal/Kg.

Total heat available 121.2 K Cal/Kg

For 1000 Kg blowdown per hour, steam at 0 Kg/cm² = \[
\frac{121 \cdot 2 \times 1000}{538 \cdot 9} = 224.9 \text{ Kg/hr}
\]

(ii) Boiler pressure is 32 Kg/cm² and total heat content of blowdown water is 245.5 K Cal/Kg.

-100.00 Heat in vapour at 0 Kg/cm²

\[145.5 \text{ K Cal/Kg heat available from blowdown}
\]

per hour steam of 0 Kg/cm² from blowdown

\[= \frac{145 \cdot 5 \times 1000}{538 \cdot 9} = 270 \text{ Kg.}\]
Without installing heat exchangers it is possible to recover this heat from blowdown by connecting it to flash tank which in turn can be suitably connected to low pressure exhaust main or vapour line with zero or below atmospheric pressure.

(ii) **Vapour recompression**—Two types of devices for utilising the latent heat of low pressure vapour from evaporator and to boost the pressure of vapour are—

(a) Thermo-compresser and

(b) turbo compressor.

In former, low pressure vapour is mixed with high pressure steam by means of an injector while in the latter case the pressure of vapour is raised by employing turbo compression. Thermal recompression is best applied at first effect of evaporator or vapour cell for upgrading the exit vapour energy. The resulting vapour of higher pressure can be reused in the calandria or even mixed with exhaust steam. Thermocompressors involve no extra power and are inexpensive for maintenance. It is preferable to provide number of nozzles for the high pressure steam injector.

The mechanical recompression requires installation of compressor driven by electric motor or steam turbine. The mechanical energy involved in this compressor is lower than the heat energy recovered in vapour. Thermo compressors or turbo compressors though introduced decades back in sugar industry have not been installed in a big way but the system of vapour recompression has attracted attention of the technologists in recent years for achieving higher energy saving in process.

(lit) **Continuous pans**—In batch operation of pans, which is well established in sugar manufacture, the steam washing of pans is resorted to, every time pan is dropped and the steam consumption can increase due to uneven feed coupled with lack of attention to pan feeding, crystal growth or fluctuations in the operating parameters. These problems are to a large extent eliminated in continuous boiling which has recently been established in sugar industry. Continuous pan boiling in which the feed and discharge are regulated by suitable automation devices has the merit of uniform and steady working conditions. For low grade boiling continuous sugar boiling offers special advantages with regard to uniformity of results and steam consumption.

(iv) **Falling film evaporator (F.F.E.) bodies**—In recent years use of F.F.E. bodies as pre-evaporator and first body of multiple effect evaporators has been found helpful in Indian Industry.

**9. BOLD GRAIN PRODUCTION**

In certain parts of India consumer preference for bold sugar grain has made it obligatory on the part of the producers to manufacture a certain percentage of the sugar with grain size of 0.8 to 1.2 mm. Production of bigger size grain necessitates:

(i) Boiling 'A' massecuites in high purity medium,
(ii) reprocessing small grain sugar (0.6 mm) as seed,
(iii) melting of sugar from low grade strikes.

This increases the total boiling by 5-7% with corresponding rise in steam demand. To satisfy the consumer demand for bold and lustrous grains, the factories have to provide extra pan capacity and to offset the increase in the steam consumption must resort to—

(i) use of vapour for pan boiling
(ii) control on use of water in pans
(iii) Special steam economy measures as outlined above.

10. STEAM CONSUMPTION TARGETS

In white cane sugar manufacture previously steam consumption of 60% on cane (in terms of steam of 538.9 KCal/Kg, heat) was considered to be quite satisfactory two decades back. In the past two decades greater awareness to conserve energy and save as much bagasse as possible for being used as raw material for paper industry or for generation of extra power for other industries and public utility has impelled the factorise to adopt energy saving methods like—

(i) elaborate use of vapour from evaporator
(ii) installation of high pressure boilers
(iii) rigid control on process operations.

As a result of adoption of various steam saving devices it has become possible to manage white sugar manufacture with 50-55% steam (of 538.9 KCal/Kg, heat) and in some factories even with 45 to 50% steam consumption. In future by copying the example of Beet sugar industry it should be possible to manage with 40-45% steam consumption without in any way sacrificing the operating efficiency or the quality of final product.
REFERENCES


2. Oliver Lyle 'Efficient use of Steam' 1956 p. 119.


5. Ibid p. 852.

### TABLE
STEAM AND HEAT BALANCE

(I) **Steam Consumption**—

1. Crushing rate 100 t/hr. Cl. Juice % cane 100
2. Quadruple effect Evaporator without any vapour bleeding
3. Cl. Juice brix % = 15.0 Syrup brix % = 60
4. Steam requirement Steam of 0.5 Kg/cm²

   
   (i) Juice heaters & 12.84 t  
   (ii) Clear juice heating & 1.69 t  
   (iii) Evaporator & 18.75 t  
   (iv) Pans & 22.00 t  
   (v) Miscellaneous & 5.0 t  

       **Total** & 60.28 t

   **Vapours to Condenser** & 40.75 t

(II) **Heat Balance**—

1. Power for mills and turbo generator & 6.80
2. Heat energy for process & 70.01
3. Heat in vapours to condenser & 23.19

   **Total** & 100.00

With vapour bleeding heat lost in vapours to condensor is reduced and the total energy requirement in reduced.
1.1. Use of condensate—The source of water for steam generation in the boilers is mostly the condensate from the heat exchangers in the boiling house of Cane Sugar factory and these condensates are of two types—

(i) Water from steam condensed in the heat exchangers.

(ii) Condensates derived from condensed vapour obtained from juice boiling in the evaporators.

The first type of condensate is ideally suited as boiler feed since it is highly pure being produced from boiler steam but the second type i.e. the condensate from vapour besides containing the volatile matter distilled off from juice in the different stages of evaporation is likely to be contaminated with sugar bearing juice. The juice contamination results from—

(a) entrainment from the evaporator bodies

(b) likelihood of damage to calandria tubes of bodies in which juice boiling takes place.

These two types of condensates are separately collected and the condensate from calandrias of bodies heated by steam is invariably sent to boiler feed tank. However not all the steam generated is condensed but due to—

(a) blowdown

(b) direct use of steam in process

(c) leakage or loss to atmosphere,

the deficiency in the condensate from condensed steam to the tune of 5-10% is made up from the condensate from second body of evaporator or other heat exchangers like juice heater etc. heated on vapour from first body of evaporator. It is only when both these condensates are not available at the time of commencement of the crushing campaign or on account of a prolonged stoppage that the sugar factory will resort to use of raw water.

1.2. In regard to maximum use of condensate for boiler feed purposes following steps are considered essential—

(i) Condensate from juice vapour to be used for boiler feed make up should be tested often for pH and sugar traces.

(ii) the above condensate should be completely isolated from condensate from steam.

(iii) Condensate rendered surplus after meeting the process demand should be separately stored in a tank to be used for boiler feed in the event of shortage of all condensates to avoid use of raw water as far as possible. At any time if condensate contaminated with juice finds its way to the boiler feed the pH of boiler water goes down due to
decomposition of the sugars and other organic matter, moreover the carbonaceous material gets deposited inside the boiler tubes. In such event the factory operation is disrupted until the boiler water quality becomes normal after the necessary blow down and replacement of contaminated water by pure good quality condensate.

2. Boiler water and boiler feed water quality norms have been specified for different pressures of boilers operation and it is absolutely essential to rigidly follow the quality standards of water for smooth boiler operation.

The problems encountered on account of deviation from the quality standard, in so far as they disrupt the smooth functioning of boiler station in cane sugar factories are as under—

(i) Pitting—Corrosion of the internal surfaces of economisers, piping and drum of the boiler, commonly termed as pitting is caused by low pH coupled with presence of oxygen and carbon dioxide in the feed water. This pitting due to corrosion brings about uneven damage to the boiler metal surfaces.

(ii) Caustic embrittlement—This signifies intercrystalline cracking of boiler steel below water line produced by high concentration of caustic soda solutions which attack grain boundaries. Irregular cracking which can be detected under microscope renders the metal brittle and weak resulting ultimately in boiler failure. This embrittlement occurs only in rivetted boilers and modern boilers with welded drums are comparatively free from this problem.

(iii) Foaming—Foam is produced on the surface of boiler water due to presence of organic matter in the water as also high amount of finely divided and suspended matter. This is related to surface tension. Foam or froth generation induces priming with the deleterious effects on primemovers.

(iv) Priming—Priming refers to the phenomenon of water being carried with steam into pipelines. It is caused by

(a) high level of water in boiler drum which reduces the effective steam separation space at full evaporation rates.

(b) high concentration of salts in solution,

(c) high suspended matter in boiler water.

Foaming and priming cause carry over of water into steam pipes and subsequently to primemovers. The carry over of solids to primemovers causes deposit accumulation on turbine blades and engine cylinders. The deposits eventually cause damage to primemovers.

3. FEED WATER & BOILER WATER TREATMENT

3.1. Feed water treatment is classified broadly into two categories viz.
(a) internal treatment and

(b) external treatment.

In the case of internal water treatment chemicals are introduced into the boiler water and the precipitated salts are removed in boiler blow down. In external treatment the raw water is treated with chemical reagents in steel tank to eliminate the salts in solution. Sometimes chemical treatment is accompanied by ion exchange treatment for removing undesirable components from water. In boiler, evaporation of water takes place under influence of heat transfer from the combustion gases of the furnace and it is essential that the heating surfaces of the boiler are clean during operation.

3.2. Internal Treatment—Any treatment of feed water or boiler water aims at removing

(i) calcium and magnesium salts contributing to hardness

(b) acidity

(c) fatty matter or oils

(d) dissolved gases,

besides reducing the dissolved solids and maintaining certain level of alkalinity.

The chemical reagents commonly added to boiler water are mainly of

(a) phosphates

(b) alkalies and

(c) other compounds including starch,

(a) In phosphates are included trisodium phosphate

(Na₃PO₄ 12H₂O) disodium phosphate

(Na₂HPO₄ 12H₂O Na₂HPO₄ 2H₂O, Na₂HPO₄)

and sodium hexametaphosphate Na(PO₃)₆.

The phosphates precipitate the calcium and magnesium salts and thereby bring down the hardness, Trisodium phosphate Na₃PO₄ also serves to increase alkalinity of water.

Alkalies normally used are Sodium hydroxide NaOH and Sodium carbonate Na₂CO₃ which maintain certain level of alkalinity for preventing damage to metal of boiler due to corrosion. Sodium sulphite and hydrazine are added in small doses for eliminating dissolved oxygen in water. Sodium sulphite Na₂SO₃ and hydrazine NH₂ NH₂ being reducing agents react with oxygen in water. Starch addition is mainly aimed at proper coagulation of the precipitated components of hardness and their easy removal.

In a special small tank installed near the boiler feed tank and pump, a solution of chemicals is made with definite concentration and is introduced into the boiler by chemical dosing pump or by suction through eductor into the feed line to the boiler after feed pump. Where a series of boilers is in operation dosing should never be common for all boilers since it would lead to unknown distribution of chemicals to the boilers and
when all the boilers are served by one feed pump it is desirable to connect the chemical delivery lines to individual feed lines of boilers.

A day's requirement of chemicals shall be met by preparing sufficient quantity of solution in day time. It needs to be stressed in this behalf that the dosing of chemicals has to be dictated by the results of analysis of boiler water and feed water at regulate intervals as it is essential to maintain quality norms of boiler water in respect of various components as given in Table 1.

3.3. External Treatment—

3.3.1. When water from condensates for boiler is not available or is inadequate, raw water has to be used for boiler feed purposes. The raw water often contains impurities derived from the source from which it is received and would thus need treatment before it can be suitable as boiler feed water.

The major impurities in raw water are the salts of calcium and magnesium which impart hardness to it as also silica, organic matter and impurities in suspension. The calcium and magnesium salts which form deposits of scale on the heating surfaces of the boiler drum and tubes retard the heat transmission and have therefore to be eliminated first. There are two principal methods for achieving this, one is the chemical treatment and the other by ion exchange method.

3.3.2. Chemical Treatment—There are two types of hardness in raw water—temporary or bicarbonate hardness and permanent hardness contributed by sulphates of calcium and magnesium. While the former caused by presence of bicarbonates of calcium and magnesium can be removed by heating or lime treatment whereby bicarbonates are converted into insoluble carbonates, the latter require to be precipitated out by sodium carbonate in accordance with following equations.

\[
\text{Ca} (\text{HCO}_3)^2 + \text{Ca} (\text{OH})_2 \rightarrow 2\text{CaCO}_3 + 2\text{H}_2\text{O}
\]

\[
\text{Ca} (\text{HCO}_3)^2 \text{heat} \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2
\]

\[
\begin{align*}
\text{Ca} & \quad \text{SO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + \text{Na}_2\text{SO}_4 \\
\text{Mg} & \quad \text{SO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{MgCO}_3 + \text{Na}_2\text{SO}_4
\end{align*}
\]

Cold lime soda treatment brings down hardness to around 80 ppm. while when these reactions are brought about in hot water the hardness is reduced to 20 ppm. The precipitation of hardness salts and their removal also helps in eliminating the suspended impurities. Addition of alum or sodium aluminates or ferric or ferrous sulphates accelerate the coagulation of suspended and colloidal matter. Sometimes this treatment can be supplemented by nonionic or cationic polymers for precipitation of the colloids. For boilers of high pressure or medium pressure exceeding 12 Kg/cm² it is essential to remove the residual hardness by ion exchange treatment.

To the reaction tank containing raw water, dilute milk of lime and soda solutions are added and the reactants thoroughly mixed with water. Partial settling followed by filtration in a pressure filter eliminates the precipitated salts as also the suspended impurities.
3.3.3. Ion exchange—A base exchange process: softening of water by natural zeolite (sodium aluminium silicate) is an old process in which the Ca\textsuperscript{2+} or Mg\textsuperscript{2+} ions in water are replaced by Na\textsuperscript{+} ions while the calcium and magnesium ions are retained by the zeolite. Once the exchange capacity is exhausted the ion exchange between water and zeolite or base exchange resin will cease and it is necessary to regenerate the same. Regeneration is effected by treating zeolite resins with solutions of sodium chloride whereby the sodium replaces the Mg\textsuperscript{2+} and Ca\textsuperscript{2+} ions in the resin which are drained out as chlorides of magnesium and calcium. Synthetic resins have now a days become more common and have replaced the natural zeolites.

The above system is applicable when the factory is to start operation after the end of the prolonged shut down as in the offseason.

3.3.4. In the hot precipitation method, two stage treatment is resorted two. In the first stage lime and soda solution are added to raw water when the calcium carbonate and magnesium carbonate are precipitated out and the separation of these precipitates is followed by dosing of mono or disodium phosphate to further lower down the hardness to few parts per million parts. The reaction with phosphate follows the following sequence.

\[
\text{NaH}_2\text{PO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{Na}_3\text{PO}_4 + \text{H}_2\text{O} + \text{CO}_2
\]

\[
3\text{CaCO}_3 + 2\text{Na}_3\text{PO}_4 \rightarrow 3\text{Na}_2\text{CO}_3 + \text{Ca}_3(\text{PO}_4)_2
\]

Tricalcium phosphate is precipitated out but additional carbonate alkalinity is introduced.

Lime soda treatment followed by ion exchange using cation exchange resins is comparatively economical for installation as well as operation.

For water containing high amount of silica softened water is first passed through cation exchange resin bed for removal of calcium and magnesium ions and then passed through strong base ion exchange resin in hydroxide form for removal of silica. Complete deionisation of water by resins can be accomplished by either of two methods.

(i) Cation exchange by treatment with cation exchange resins followed by removal of anions and silica by passage through anion exchange resin bed.

(ii) Passing water through monobed resins in which both cations and anions are removed.

This technique involves allowing water or any solution containing electrolyte to pass through a mixed bed of cation exchanger in hydrogen form and anion exchanger in hydroxide form whereby complete deionisation is effected. The water to be subjected to ion exchange treatment must be free from suspended impurities and turbidity. Water treated with alum and passed through sandbed for eliminating turbidity and impurities in suspension can be passed through resin beds.
4. SIGNIFICANCE OF CONTROL

4.1. The significance of treatment of feed water and boiler water lies in the fact that various constituents which either retard heat transmission or affect the metal of boiler need to be eliminated and since boiler is a unit on which the entire cane sugar factory operation is dependent the importance of maintaining rigid control on boiler water can never be over emphasised. The rationale behind exercising control on different impurities in the context of cane sugar factory operation is briefly explained below—

(i) Oxygen—Oxygen remains in dissolved state in water and becomes less soluble as temperature of water rises. Oxygen causes corrosion of metal surface with the resultant pitting of the surface of tubes. The dissolved oxygen content of water at different temperature is as under—

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>Solubility m.l./litre</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.89</td>
</tr>
<tr>
<td>50</td>
<td>2.1</td>
</tr>
<tr>
<td>60</td>
<td>1.65</td>
</tr>
<tr>
<td>70</td>
<td>1.3</td>
</tr>
<tr>
<td>80</td>
<td>0.95</td>
</tr>
<tr>
<td>90</td>
<td>0.65</td>
</tr>
</tbody>
</table>

(Based on graph in 'Efficient use of steam' by Oliver Lyle 1947 p. 805.)

The deaeration can thus best be brought about by heating the feed water in the feed water tank, to boiling point for reducing the oxygen content to minimum level, by installing steam pipe in the tank. This heating will drive out O₂ and CO₂. The residual quantity of oxygen can be eliminated by scavenging chemicals like sodium salphtie or hydrazine. Sodium sulphite forms sodium sulphate with O₂ while hydrazine reacts with O₂ to form N₂ and H₂.

(ii) pH—Corrosive action of water is minimum when the pH is distinctly on the alkaline side i.e. 8 and above. At pH 9.0 protective film of ferrous hydroxide is formed. Sometimes condensates owe their alkalinity to dissolved ammonia released on evaporation of juice in evaporator. This water when heated in boiler will release ammonia with drop in pH. Thus frequent pH checking is essential and needs to be rectified whenever necessary.

(iii) Caustic alkalinity—Bicarbonates and carbonates impart alkalinity to water and pH alone does not provide indication regarding the amount of bicarbonate or hydroxide. Bicarbonates are objectionable as under influence of heat bicarbonates like carbonates decompose to form CO₂ according to equation—

\[ 2\text{HCO}_3^- \text{heat} \rightarrow \text{CO}_2 + \text{CO}_3^- + \text{H}_2\text{O} \]
\[ CO_3^- + H_2O \xrightarrow{\text{heat}} CO_2 + 2OH^- \text{ hydroxyl ion} \]
\[ CO_2 + H_2O \rightarrow H_2CO_3 \]

The carbonic acid reacts with steel and corrodes it forming ferrous bicarbonate

\[ Fe + 2H_2CO_3 \rightarrow Fe(HCO_3)_2 + H_2 \]

To prevent corrosion from carbon dioxide some minimum caustic alkalinity needs to be maintained in the boiler water as per the limits specified. The caustic or hydroxide alkalinity serves to prevent corrosion and maintain silica in solution.

(iv) Hardness and dissolved solids—As stated elsewhere hardness of water caused by the presence of carbonates, bicarbonates, chlorides or sulphates of calcium and magnesium leads to deposition of scales on the tubes. The scales which are poor conductors of heat affect the operation in two ways—one heat transmission is retarded and boiler efficiency is lowered two—overheating of tubes can take place on account of poor heat transfer from hot gases to water. Silica in water in boiler can deposit on internals surface as hard scale which would give rise to the same problem as above.

During evaporation of water in boiler the solids in solution are concentrated in boiler water and unless removed by blowdown can lead to priming or carry over. If blowdown is too little the solid sludge in boiler can cause problem but excessive blowdown will lead to loss of heat energy and reduction in boiler efficiency. Continuous and automatic blowdown is desirable based strictly on dissolved solid concentration.

To optimise boiler efficiency it is essential to minimise the blowdown by improving control over blowdown and improving feed water quality. Blowdown control will reduce the use of condensates from juice vapours or raw water. For boilers operating at high pressures (about 30-40 Kg/cm\(^2\)) rigid control on blowdown has to be observed and this can be accomplished by automatic control of this operation together with adherence to quality norms for boiler water to suit the boiler pressure.

5. ANALYTICAL CONTROL

5.1. For effective control of feed water and boiler water frequent analyses of these are to be carried out in the laboratory and proper records maintained. Needless to state that the internal conditioning of water and the dosing of reagents has to be guided by the analytical results. The analyses to be conducted are as under—

(i) Feed water—pH, caustic alkalinity, total alkalinity, hardness-twice daily.

(ii) Boiler water—pH, caustic alkalinity, total dissolved solids and suspended impurities,-twice in a day.*

(iii) Sugar test and pH should be checked once in two hours for both feed water and boiler water.

(iv) In feed water silica and sulphates should be estimated once in a day.
The analyses have to be carried out in accordance with standard methods of analysis.

5.2. Sugar in the condensate—In canesugar mills since condensates are used for boiler feed and the make up water is usually condensate from 2nd body condensates, sometimes sugar enters this condensate due to entrainment in the first body of evaporator. Besides leaks in the tubes contribute to the contamination of condensate with juice. Sugars are decomposed due to highly alkaline conditions and heat in the boiler, into corrosive acidic compounds which are detrimental to the tubes and shells of boilers. Sucrose is decomposed into organic acids and humic acid which forms humic compounds injurious to boiler steel.

Sugar contamination leads to dark colouration of boiler water which then gives a characteristic odour. The only remedy lies in replacing the water with good quality clean water and giving frequent blow down.

5.3. In table 1 are given recommended parameters to be maintained in respect of various important characteristics of both feed water and boiler water which serve as guide lines for the staff responsible for quality control of boiler water. However, it is essential that instructions of boiler manufacturers are taken into account and followed in respect of boiler water characteristics, as it must be borne in mind that the quality control and treatment of feed water as also the boiler water are aimed at safety of equipment (b) smooth operation and (c) high efficiency of boiler.

5.4. Flue gas analysis—The proportion of CO\(_2\) in the flue gas is dependant on the excess air supplied for combustion and will be less when the excess air supply is more and the maximum CO\(_2\) content attainable theoretically is 19.8\%. However for completion of the reaction of carbon dioxide formation and to prevent formation of CO which affects adversely the efficiency of boiler, optimum CO\(_2\) content in flue gas in bagasse fired boilers is considered to be 12 to 14\% with an excess air of 25-50\% and experience in different countries shows that below 12\% CO\(_2\) the efficiency loss is discernible. Of equal importance is the upper limit of CO\(_2\) content is flue in as much as one percent CO in the gas results in loss of 4.4 - 4.5\% calorific value of bagasse.

It is essential to analyse frequently the flue gases for both CO\(_2\) and O\(_2\) to understand the combustion and heat efficiency of the entire system. In modern boilers instruments serve to indicate the Oxygen and carbon dioxide content of flue continuously.


### TABLE

**QUALITY OF WATER FOR BOILERS**

<table>
<thead>
<tr>
<th>Operating pressure</th>
<th>30 bar</th>
<th>45 bar</th>
<th>60 bar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feed water</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) pH</td>
<td>8.5-9.5</td>
<td>8.5-9.5</td>
<td>8.5-9.5</td>
</tr>
<tr>
<td>(2) Dissolved oxygen</td>
<td>&lt;0.05</td>
<td>&lt;0.02</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>(3) Total hardness</td>
<td>&lt;2</td>
<td>&lt;1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>(4) (i) Total dissolved solid</td>
<td>such that excessive blowdown</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ii) Total alkalinity</td>
<td>is avoided and blowdown required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Hi) Silica</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(iv) Oil</td>
<td></td>
<td></td>
<td>Nil</td>
</tr>
</tbody>
</table>

**Boiler water**

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>1500</th>
<th>1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Total dissolved solids ppm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Suspended solids ppm</td>
<td>50</td>
<td>25</td>
<td>nil</td>
</tr>
<tr>
<td>(3) Total alkalinity (max.) in CaCO₃ ppm.</td>
<td>500</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>(4) Caustic alkalinity</td>
<td>200</td>
<td>160</td>
<td>60</td>
</tr>
<tr>
<td>(5) Silica max. ppm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>not greater than 0.4 of caustic alkalinity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(6) Sodium phosphate ppm, Na₃ PO₄</td>
<td>30-70</td>
<td>30-70</td>
<td>20-50</td>
</tr>
<tr>
<td>(7) Sodium sulphite ppm</td>
<td>20-50</td>
<td>20-50</td>
<td>nil</td>
</tr>
</tbody>
</table>

*Or*

<table>
<thead>
<tr>
<th>Hydrazine</th>
<th>0.1-1.0</th>
<th>0.1-1.0</th>
<th>0.1-0.5</th>
</tr>
</thead>
</table>

From the Efficient use of steam Editor P.M. Goodall published by Westbury House 1980 p.133.
STEAM CONSUMPTION AND STEAM ECONOMY MEASURES

BOILER FEED WATER

Steam from boilers 100

80—90 condensed in process

10—20

5% blowdown

2—5% direct use

Wastage 2 to 10%

80—90 condensate
from steam
from process house

10—20 2nd body of evaporator condensate for boilers of upto 21 kg/cm² pressure

100 to boiler feed water tank

or

Raw Water
(a) Softened
(b) deionised in Ion Exchange resins for boilers of pressures of 32 kg/cm² and above
PART-III

STEAM GENERATION

1. PROPERTIES OF STEAM

1.1. In sugar mills steam is used for both power generation and as source of heat in process operation. Some of the fundamental properties of steam which govern its use for generation of power and for heating as well as boiling in process are—

"(i) High pressure and temperatures of steam are desirable for generating power.

(ii) Low pressure steam is required in process operation.

(Hi) Latent heat of steam increases as pressure is reduced.

High pressure steam from boiler is fed to prime movers for some units like mills also to the power generating turbines and the exhaust steam from these prime movers is utilised for process operations. In modern plants this exhaust steam supplies 80-90% of the needs of boiling house.

1.2. Water is transformed into vapour phase by external supply of heat from fuels and the heat supplied performs the function in three ways—

(i) Gives sensible heat for raising the water temperature to boiling point.

(ii) Provides latent heat for formation of vapour phase for transforming water at boiling temperature into steam.

(iii) Super heating the steam beyond that corresponding to saturation temperature of steam.

Thus saturated steam is in complete vapour phase when it is free from water and the dryness fraction indicates the water content of the steam as for instance dryness fraction of 0.95 indicates 5% water content of steam. The superheated steam is at a higher temperature than the saturated steam of the same pressure and is absolutely essential for turbines as it is moisture free and has higher heat content.

In modern factories the common practice is to generate steam at 21 Kg/cm² pressure with, a degree of superheat of 70-80°C i.e. at a temperature of around 300°C. Recent trends favour installation of boilers generating steam at 31 or 45 Kg/cm² pressure and super heat of about 150°C since high pressures are conducive for higher power generation. The exhaust steam from the prime movers is of about 0.7 to 1 Kg/cm² and is entirely used for heating and boiling in the process.

1.2. Live steam is used in two ways in sugar mill—

(f) for driving turbines or engines

(it) directly for process at reduced pressure to make up for the shortage of exhaust and also at centrifugal station and for sulphur furnace.

The live steam directly used in process is the boiler high pressure steam passed through.
reducing station for reducing pressure to 5 Kg/cm². In this way the steam generation in sugar mill serves two fold objectives—

(a) generating power for machinery operation and

(b) providing heat energy for the process of sugar factory.

2. BAGASSE

The residue of cane after juice extraction, known as bagasse is the most common fuel used in cane sugar manufacture. The proportion of bagasse produced per 100 tonnes of cane crushed varies from 25 to 32, usually lying around 27-28%. The fresh mill bagasse contains 48-50% water, 2.5 - 3.5% dissolved solids or brix and 46 - 48% fibre. The brix or the dissolved solid in bagasse has its origin in the cane juice while the fibre constitutes the insoluble cellulosic matter of sugar cane. The chemical composition of moisture free bagasse as given by different authors shows wide variations and Hugot has taken following mean values.¹

Carbon 47% Hydrogen 6.5%, Oxygen 44%, Ash 2.5%, total 100, Calorific value i.e. heat generated by combustion of a unit weight of bagasse is expressed in two ways viz. gross CV. and net C.V.

The gross or higher calorific value is the heat generated by combustion of one Kg. of bagasse the products of combustion being reduced to the conditions of 0°C under 760 mm of mercury. The water vapour formed as a result of combustion of hydrogen as also the water present in bagasse is condensed under these conditions.

The net calorific value or the lower calorific value is based on the condition that water generated due to presence of hydrogen or the water accompanying bagasse is presumed to be in vapour state.

The gross CV. gives the amount of heat theoretically liberated but the net CV. serves to indicate the heat available under practical conditions. The formulae for arriving at the CV. of bagasse taking into account the major components are as under—

For wet bagasse—G.C.V. = 4600 - 12S - 46 W

G.C.V. is gross calorific value in KCal/Kg

N.C.V. = 4250 - 12S - 48.5W  N.C.V. is net calorific value in KCal/Kg.

S = Sucrose % bagasse  W = Moisture % of bagasse. For dry bagasse G.CV. 4600 KCal/Kg and N.CV. = 4250 KCal/Kg.

For pith from bagasse calorific value is 93% of that of bagasse. The above formulae show the part played by dissolved solids and water in reducing the heat value of bagasse and out of these water content has profound influence on the heat value.
3. COMBUSTION OF BAGASSE

Air furnished for combustion of bagasse contains 23.15% Oxygen and 76.85% nitrogen and other inert gas by weight. On volume basis the corresponding percentages are 20.84 and 79.16 respectively. Combustion of bagasse involves following reactions

\[ \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \quad \text{H}_2 + \text{O} \rightarrow \text{H}_2\text{O} \]

Some excess air over that theoretically required for above reactions has to be supplied in practice for completion of reactions in view of the fact that conversion of C to CO will yield only 2361.0 KCal/Kg. as against 8000.0 KCal/Kg. obtained by formation of CO\(_2\). The free gas from the boiler chimney will therefore contain apart from CO\(_2\), oxygen from excess air, nitrogen and water vapour. In modern boilers optimum efficiencies are obtained with CO\(_2\) content of the gases of 12-15% and excess air varying from 25-50%.

The heat evolved as a result of combustion of bagasse is taken up by the gases and a major portion of it transmitted to the boiler, the remaining being accounted for mainly by the heat in flue gas and to a small extent radiation loss and boiler blow down.

The temperature of the furnace in efficient boiler ranges between 1100°C to 1200°C. This combustion temperature decreases with higher excess air and increases with higher temperature of the ambient air. Moisture in bagasse has adverse influence on the temperature of combustion.

As stated earlier the most important heat loss in the entire boiler unit is the sensible heat contained in the outgoing gases. This heat loss in flue gases increases with—

(a) temperature of flue
(b) moisture of bagasse and
(c) percentage of excess air.

In practice out of the total heat obtained in combustion of bagasse in furnace, the losses take place as under—

(i) Loss of sensible heat in flue
(ii) Loss in unburnt solids
(iii) Loss due to incomplete combustion resulting in formation of CO instead of CO\(_2\)
(iv) radiation loss.

Taking all the above losses into account the heat transferred from fuel to steam is around 66% of the heat theoretically obtained under certain standard conditions of temperature and pressure. In practical terms this is stated as overal efficiency—

- Heat units transferred to steam
  G.C.V. of bagasse burnt.

4. As regards the other fuel used, wood, coal and fuel oil are occasionally used as supplementary fuels and their calorific values are as under—
N.C.V. of wood 2500 K Cal/Kg.
N.C.V. of coal 6105-7770 K Cal/Kg
N.C.V. of fuel oil 10,000 K Cal/Kg

In the light of above special characteristics of bagasse as fuel, for attaining high levels of efficiency by reducing losses following features have been incorporated in modern designs of boiler—

(i) Supply of preheated air
(ii) Raising the temperature of boiler feed
(iii) reducing the moisture content of bagasse
(iv) ensuring thorough mixing of air and bagasse.

Besides these, higher pressure and temperatures of steam are conducive to maximum heat recovery.

The most important sections in boilers are the furnace wherein the fuel consumption takes place and the steel boiler with drum and tubes in which the water is transformed into steam.

5. FURNACES

5.1. Some characteristics of bagasse burning in boiler furnaces are—

(i) bagasse contains around 45-50% moisture which is to be eliminated before combustion and gas formation will commence.
(ii) Bagasse burns with long flame and it is imperative to provide adequate combustion chamber volume for ensuring thorough mixing of fuel components with air.
(iii) When a mill stops for a short period during running, flow of bagasse from mills is disrupted and to keep the boiler running alternate arrangement for feeding bagasse is required in a sugar factory.

5.2. The major types of furnaces are as under

Step grade furnace—The grate inclined at 52° to the horizontal is made up of small C.I. plates arranged in steps. The grate can be distinguished by three parts—the upper part with steps which is known as dead plate on which the bagasse is dried as it drops from chute, followed by step grate where the burning of bagasse starts and finally the ash gate at the lower end on which the combustion is completed and from which ash is discharged through the openings into a pit below. This ash grate is inclined at 20°. This type of furnace was quite common in old boilers working at 12-14 Kg/cm² pressure.

52. Horse Shoue furnace—In this type of furnace which takes the form of horse shoe bagasse falls from the chute in a pile on the hearth. Air is blown from outside through tuyers or openings around the furnace for combustion. The air can be cold or preheated. The ash
accumulating at the bottom of hearth is removed from the ash doors. Compared to step grate, high combustion rates and efficiencies are attained in this type of furnace.

5.3. Ward furnace—Similar in structure to the above described horse shoe furnace, it has CI. hearth and bagasse burns in a pile. Special feature of this type of furnace is the conical arch with restricted throat between the hearth and the large boiler chamber. In modern furnaces preheated air is supplied through openings at several points in the lower and upper portion to bring about intimate mixing of air with the fuel. In modern designs ash removal at periodical intervals is effected through dumping grates below the hearth to reduce the cleaning time.

5.4. Spreader Stoker furnace—This design is comparatively of recent origin which has a special feature associated with feeding of bagasse. Bagasse is fed through a sloping chute while air blast supplied from behind the chute throws the bagasse into the furnace, the coarser particles completing their combustion on the grate. With bagasse combustion in suspension the excess air requirement is low—around 30% and grate area provided is low. Moreover the ash removal is easy. But the unburnt fuel loss can be around 2.5 - 3%.

5.5. Water cooled inclined grate—Foster Wheeler developed water cooled version of inclined grate furnace. Bagasse is charged at the top end of inclined furnace and it slides down getting dried, while in the last section volatile matter is released and carbon combustion takes place. The ash removal is effected through the dump grate. Intense water cooling arrangement allows high temperature of air (300°C) to be admitted without any adverse effect on the furnace. The grate bars are cooled by water tubes which form part of boiler circuit. The clinker formation is prevented in this water cooled furnace.

6. BOILERS

6.1. Modern water tube boilers are mainly of two types

(i) Straight tube boilers and

(ii) bent tube boilers,

In these boilers, banks of tubes which constitute the heating surface lead into two or more drums. In straight tube boilers rows of straight tubes are connected to headers and to the drum. In bent tube boilers as the name indicates, tubes inclined to the horizontal are used which promotes efficient circulation of water. In designs with straight tubes cleaning and replacement of tubes is easier while with sloping tubes replacement is difficult. The diameter of tubes is usually 65-80 mm the bent tubes being usually of smaller diameter than the straight ones.

6.2. Economisers—The condensate used as feed water in boiler in cane sugar factory is at a temperature of about 90°C while the saturation temperature of steam is much higher than this. As the boiling point of water increases with pressure the boiling point will be 213.9°C at 21 Kg/cm², 234.6°C at 31 Kg/cm² and 250.6°C at 41 Kg/cm² i.e. the boiling pressure usually encountered in cane sugar mills. Heating the feed water of 90°C to such high temperature would take considerable amount of heat of the combustion gases. The
feed water is made to pass through heat exchanger consisting of bank of tubes positioned in the path of flue gases after they leave the boiler on the way to chimney. This heat exchanger is known as economiser through which feed water is passed before entry into boiler. The economisers are usually made of cast iron and their function is essentially to heat the feed water and not to boil it. Recommended practice is to maintain a difference of 30°C between the economiser outlet and the boiling point corresponding to the boiler pressure as a matter of safety.

6.3 Air preheater—For further recovery of sensible heat from the flue gases during their passage to crumney a special equipment is installed in which air used for combustion of fuel in the furnace is heated. The construction of this equipment known as air pre-heater is of two types—

(i) tubular

(ii) plate types.

Air heaters are located in the flue passage after the economiser and unlike the economiser operate at atmospheric pressure. Preheated air improves the combustion of fuel and according to Hugot the combustion temperature increase in the case of bagasse furnace is 60% of the rise in temperature of air.²

Recovery of heat from the gases going to chimney is accomplished by both economiser and air preheater which have found important place in the present day high pressure or even medium pressure boiler installations. The dew point of the combustion gases is around 60°-65°C and the fear of condensation on the exterior of air heater does not exist. In practice it is possible to bring down the temperature of flue gases to 150°-180°C in boilers equipped with economiser and air preheaters.

6.4 Superheaters—For efficient operation of prime movers like turbines it is essential to use superheated steam. Superheater of boiler is a bank of tubes suitably located in the path of hot gases and connected to the boiler drum. In the superheater of a boiler saturated steam is received from the boiler and at the outlet the superheated steam is sent out into the live steam mainline. The degree of superheat varies from 100°-200°C for boiler pressures of 21-31 Kg/m² depending on the operating pressure of boilers as also the requirements of electricity and power of prime movers.

7. ACCESSORIES

1. Boiler feed tank—A cylindrical feed water tank located at a height of about 7m from the ground receives the condensates from the boiling house. The capacity of this tank is related to the capacity of the factory and in order to take care of fluctuations in steam demand sufficient capacity has to be provided. The recommended standard for capacity is reckoned to be 0.1/t cd.³

The feed water tank is connected to feed pumps of sufficient capacity and designed to develop at least 25% higher pressure than the boiler pressure.
For removing dissolved oxygen in the feed water deaerator is installed where the water is heated to 100° -105°C

7.2. Fans—There are two types of air supply system to boiler furnaces.

(i) induced draft and

(ii) forced draft, for which fans are installed.

In the induced draught, the fan is located in the flue passage to chimney to draw gases from the boiler accessories and deliver them to chimney. In the other systems air is blown into the grate and this is known as forced draught. This is normally installed with air preheaters in the case of horseshoe or Ward or spreader stoker furnaces.

7.3. Fly ash arresters—In sugar mills the unburnt solid particles carried along with flue gases settle down in the neighbouring areas and cause environmental pollution. The factories have to install flyash arresters to meet this problem. This equipment installed in the flue passage operates on the principle of centrifugal action or change of direction of the gases.

7.4. Chimney—The waste gases are discharged through a chimney of R.C.C. or steel construction. The height of chimney is usually about 30 m to prevent the flyash from spreading in the immediate vicinity of the boiler installation.

8. RECENT TRENDS

8.1. In the last two decades the concept of exploiting the potential of bagasse for paper manufacture or as a renewable source of energy has gained wide acceptance and consequently efforts have been made to evolve systems which besides meeting the energy requirements of sugar manufacture would contribute to substantial saving of bagasse to be used as substitute for wood in the manufacture of cellulose based industry or for generating electric power for public use. Two major developments in this area are—

(i) reduction of moisture in bagasse by drying

(II) installation of high pressure boilers for surplus power generation.

8.2. Bagasse drying

8.2.1. Moisture in bagasse exerts profound influence on the heat value of the bagasse as shown by the formula N.C.V. = 4250 - 12S - 48.5 W where S and W represent sugar and water percentages respectively while N.C.V. stands for net caloritic value of bagasse in KCal/Kg. With the present trend to adopt high imbibition on mills or with diffuser system, the moisture content in final bagasse lies around 50-52 and it would be essential to bring down this moisture to as low level as possible by installing special equipment. The following table gives an idea of the increase in calorific value of bagasse with reduction in moisture content from 50% to 40% and 35%.
For drying of bagasse flue gases after the preheater or economiser can be used to recover maximum heat from exit gases of the boiler whereby their temperature is reduced from around 250° - 300°C to 100°C i.e. well above their dew point of 60° - 70°C. The drying of bagasse—

(i) decreases the air required for combustion

(ii) increases the combustion temperature of bagasse and

(iii) gives higher production of steam per unit weight of bagasse.

8.2.2. Systems of Bagasse drying—At Waiialu in Hawaii the dryer utilises flue gas before it enters the air heaters and the moisture in bagasse is brought down to 33.50% from 47.8%. In Brazil separate drying of bagasse fed to each furnace with hot gases after the air heaters has yielded drop in moisture of bagasse by 12% from 52 to 40 and capacity increase of the boiler by 20%. The stack gases after the air heater at 220°C are blown through a mixture box where they mix with bagasse. A fan pulls the bagasse mixture through a tubular column of 15 m ht. to a cyclone separator from where the dried bagasse is fed by gravity to furnace and wet gases led to chimney. K.S.G. Does put forth a novel idea of using superheated steam for evaporating bagasse moisture and using the exhaust steam liberated—

(i) for preheating air or feed water or

(ii) compressed to 0.7 Kg/cm² for process operation. In the dryer developed in Sweden high pressure saturated steam is passed through shells of heat exchangers in which wet material is conveyed. Results of Pilot plant trials of this system with bagasse are reported to be encouraging.

According to Hugot in view of the high costs of dryer the gases after economiser or air heater at temperature of 280° to 300°C should be passed through rotating drum type dryer fitted with vanes to facilitate forward movement of the bagasse along the rotary unit.

9. HIGH PRESSURE BOILERS

In the early stages of the industry, the sugar plants used to install boilers working at 11-12 Kg/cm² and generate captive power with the help of steam engines. From fifties onwards the trend was to install steam turbines and boilers operating at 21 Kg/cm².
which helped the factories achieve self-sufficiency in fuel and save good amount of bagasse. In Hawaii the need for using electric power generated in the factory for irrigation on plantation impelled the industry to generate surplus electricity by installing high pressure boilers operating at 40 to 60 Kg/cm² pressure and efficient turbines. In order to reduce the exhaust steam production in the factory also, it is imperative to feed high pressure steam to prime movers since a turbine for generating one K.W. electricity at full load requires 13 Kg. steam of 21 Kg/cm² pressure and 9 Kg steam of 31 Kg/cm² with production of exhaust steam of 1 K/cm². Thus adoption of high steam pressure for boilers has assumed special significance in order to—

(i) generate surplus electricity and to

(ii) save larger quantities of bagasse.

In keeping with this trend the modern sugar plants are installing boilers of 31 to 45 Kg/cm² pressure instead of conventional boilers of 21 Kg/cm² pressure.

As regards the capacities of boilers, from the energy conservation angle it is desirable to have large capacity boilers and the previous practice of installing boilers of 10-15 t/hr capacity is abandoned in favour of boilers of 40 t/hr capacity in Indian Industry. In Hawaii the boiler capacities of 50-150 t/hr have been reported.

10. STEAM PRESSURE REDUCING VALVES

10.1. In a thermally well balanced plant usually the exhaust steam from prime movers falls short of the requirement of process operation by 15-25% and it becomes necessary to bleed live steam into exhaust line by reducing its pressure. Moreover for direct use at centrifugals, sulphur burners and at pans the live steam pressure has to be brought down to 5 Kg/cm² from the 21 Kg/cm² normally produced in the boilers. The pressure reducing valve has a diaphragm lower part of which is in communication with the high pressure side. The pressure acting on the underside of diaphragm is balanced pneumatically. As soon as the pressure on the down side of the steam line falls below the set limit the pressure regulation opens the live steam inlet.

10.2. Desuperheater—The steam after pressure reduction has a very high degree of superheat as expansion does not bring down the steam temperature substantially and when mis reduced live steam is to be injected into the exhaust it has to be desuperheated. The desuperheater comprises small vessel in the exhaust line in which hot condensate is injected through nozzle, The water quantity is regulated by temperature control device.

10.3. Surplus valve—In a cane sugar factory where the vapour bleeding from the evaporator with or without pre-evaporator is extensively practised it is essential that the demand for steam at the evaporator station is fulfilled all the time and as the steam demand at pans is widely fluctuating, uninterrupted supply of exhaust to evaporator can be ensured only by installing a device known as surplus or overflow valve in the exhaust pipe line after the evaporator. This valve discharges only the surplus steam into the exhaust line going to pans and only when the pressure on the inlet side of the valve exceeds a certain value,
the valve opens and then permits surplus steam to pass to pans and other stations after meeting the demand of evaporator.

11. ELECTRICITY
11.1. In modern plant of cane sugar manufacture most of the units like pumps, centrifugal machines, crystallisers, etc. and cane preparatory devices as also the boiler fans are electrically driven and therefore electric power generation has to be centralised. Usually except the mills, boiler feed pumps and in some factories shredders or fibrizers, electric motors are installed to provide drive for running different units. In a central power house, electric power is generated by installing one or more turbine driven generators and from the main switch board power is distributed to different units in the factory by laying cables. In sugar factories three phase alternating current is produced.

Back pressure turbine receiving live steam at 21 Kg/cm$^2$ or 31 Kg/cm$^2$ discharges exhaust steam at 0.8 to 1 K Kg/cm$^2$ which is used in the process operation and converts nearly 10% of the heat energy of steam into electric energy. The turbine installed is designed to suit the steam pressure and temperature conditions of the boiler. The turbine is coupled to an alternator through closed reduction gear. The alternator develops 3 phase alternating current of 50 cycles/Sec. and 400-440 volts. In U.S. A. the standard frequency is 60 cycles whereas in India, Europe and some other parts of the world 50 cycles/sec. is standard frequency. The alternator speed has to be submultiple of 3000 for this frequency.

The installed electric power in modern cane sugar plants, with mills driven by turbines is usually 24 KW/tch though efficiently run plants operating at 115-120% total capacity consume 80% of the installed power.

11.2. Surplus power generation—For producing surplus electricity as a by product of cane sugar manufacture installing high pressure boilers becomes a necessity and in Hawaii raising boiler steam pressure to 31-85 Kg/cm$^2$ together with modifications in the system design of the power and steam cycle have enabled factories to release surplus power to the tune of 2 to 4 megawatts of electricity for irrigation and other purposes. For a factory with a crushing rate of 2500 t. per day by installing high pressure boilers of 31 Kg/cm$^2$ or so it is possible to generate 2 M.W. or more power for sale to state grid or other industrial units.

For new sugar projects to be set up it is possible to plan for surplus power production by installation of high pressure boilers, turbo alternators to suit the conditions of boiler steam and steam turbines for mill drive operating at high steam pressure. The boilers should operate at 41 Kg/cm$^2$ and 400°C.

For existing plants installation of high pressure boiler together with extraction/condensing turbine in which the function of back pressure and condensing are combined should be suitable and the surplus heat in the steam after meeting process demand, is converted into electrical energy. The total system design has to be carefully worked out and it is desirable to have two or three turboalternators so that in the event of shut down of any unit in the entire steam power generation system, the factory operation need not suffer.
12. Whether for producing additional power or energy or for any other industrial purposes the full potential of bagasse is to be exploited and therefore it is essential to save maximum amount of bagasse for which following major steps are considered important.

(i) Steam pressure and temperature have to be higher 31-51 Kg/cm² and 400°C respectively. The boiler design must be suitable for highly efficient operation and should incorporate heat recovery systems like air heater and economiser.

(ii) Bagasse moisture should be brought down if possible by installing dryer. At the mills bagasse moisture should be reduced to 45-47% and it should be sent out to form a heap in the open space from which by means of carrier it is conveyed to boiler. This will help further reduce the moisture by 1% or so and ensure regulated supply of fuel to boiler.

(iii) Boiler feed water must be at 95°C and conform to the standards required for high pressure boilers.

(iv) Recovery of heat from blow down of boilers and conservation as well as maximum use of hot condensates are essential.

(v) Steam consumption in process has to be controlled so that the factory can manage within 50% or if possible with 45-50% steam consumption.

(vi) Process operation has to be geared to maximum energy conservation.
REFERENCES

2. Ibid p. 921.
3. Ibid p. 933.
   also G. Fraser Ibid p. 133-136.
Fig. 1.
STORAGE OF MOLASSES

BAROMETRIC
CONDENSER

MULTIJET
CONDENSER

Fig. 2.
STEP GRATE FURNACE

Fig. 3.
HORSESHOE FURNACE

Fig. 4.
LOCATION OF SPRAY POND AND WATER CHANNELS

Fig. 5.
5. USE OF WATER IN PROCESS AND DISPOSAL OF EFFLUENTS

Sugar factories require water for all its stations except the sugar packing house, the total demand varying from 1 to 2.5 million litres of raw water for sugar mills producing 150 to 300 t sugar per day in addition to the water obtained from sugarcane. The water use in the sugar mill is of two types—

(a) the cold raw water which is mostly required for machinery as well as for cleaning and

(b) the hot water derived from sugarcane which is consumed to a large extent in the process operation.

The source of cold water for sugar mill is either nearby river or well or irrigation canal from which water is pumped to factory and stored in large tank and thus the factories have to incur expenditure on meeting cold water requirements. On the day of periodical shut down for cleaning the heating surface, considerable amount of raw water has to be used. The water discharged from the factory has to be treated to render it free from impurities objectionable from the public health point of view.

RAW WATER

The raw cold water is required in the sugar factory for

(i) cooling of bearings, pump glands i.e. for running machinery

(ii) cooling of sulphur burners and crystalliser massecuites

(iii) washing the flooring and cleaning of heating surfaces, usually juice heaters during running

(iv) washing and cleaning vessels and heating surfaces on cleaning day during shut down at periodical intervals say one day in 2 to 3 weeks

(v) testing of vessels and equipments prior to commencement of the crushing campaign.

(vi) Condensers.

All the above modes of water consumption are related to either runrung or maintenance of factory machinery and as for the process operation, in some mills raw water is being used for—

(a) imbibition along with hot condensates and

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(b) to supplement the boiler feed water in case the condensate is contaminated with juice or is inadequate.

The details of the stations where raw water is consumed are presented in Table 1. The quantities of water for cooling of bearings, pump glands etc. are subject to variations depending on the equipment design. The total raw water requirement would work out to be 1000-2000 m$^3$ per day in a factory crushing 100 - 120 tch. Out of this total water requirement, a major portion is consumed in cooling of bearings, at mills, for pumps etc. during running and comparatively smaller proportion of water is used at the sulphur burners and crystallisers etc.

3. The temperature rise of water used for cooling the bearings at mills et. is about 3° - 4°C, while that for the water leaving the sulphur burners and crystallisers is about 15° - 20°C, the temperature at discharge being around 45° - 50°C$^\dagger$. The former category of water can be reused while the latter is let out. For optimising the use of cold water in the process following steps are to be taken—

(a) The water used for cooling the bearings at mills, and other power generating units should be collected in a tank for recycling the same.

(b) The water from the sulphur station and crystalliser which is at a temperature of 45° - 50°C should be sent to condenser water cooling system, being unsuitable for recycling.

(c) All condenser water including that from the vacuum filter has to be sent to spray pond or cooling tower.

(d) Use of cold water for the imbibition at mills and also for boiler can be dispensed with during the crushing campaign. Condensate of 70° - 85°C has been found to be effective in improving mill performance and the slippage at mills due to high temperature water can be overcome by new techniques of roller arcing etc. Similarly proper conservation of condensate obviates use of cold water for boiler feed makeup.

(e) For maintaining sanitary conditions in the plant, washing of floors, platforms is unavoidable but in the absence of proper control over use of water for this purpose enormous wastage is possible. Leakages of juice bearing materials have to be attended to and stopped for two reasons one, loss of material in process means sugar loss, two, load on the effluent treatment section increases on account of higher amount of organic and soluble matter.

(f) Water requirement of crystalliser station for cooling of final massecuette is considerably brought down in continuous crystallisers, which are rapidly replacing the old batch crystallisers.

(g) the water has to be free from suspended impurities, like soil etc. and soft water is always preferable to hard water.

(f) Entrainment from pans, and evaporator last bodies and filter must be avoided. With
optimisation of the use of water and control over the process operation it is possible to restrict the consumption of raw water to 40-50 m$^3$ per 100t. cane.$^2$

4. EFFLUENT TREATMENT

4.1. The water discharged from the factory usually at the rate of 50-100 m$^3$ per 100t cane crushed has to be treated because of the organic matter and suspended impurities present, for letting it into public stream or using it for irrigation in fields. In a well managed factory the levels of impurities in the effluent discharge during plant running are approximately as under—

(i) pH5-6
(ii) B.O.D. 800-1200 ppm
(iii) Suspended matter 100-150 ppm
(iv) Oils and grease around 50 ppm

The Norms specified under public health regulations for water to be mixed with irrigation water and for letting it into public streams are given in Table 3.

4.2. Since the waste from sugar mill during operation is mostly contaminated with

(i) oils or greasy matter from the machinery
(ii) carbohydrates from the sugar bearing liquids leaking from pump glands, overflows etc.
(iii) suspended matter like small amounts of bagasse, filtercake dropping on the floor, the logical method of treatment has to be based on eliminating the suspended matter and degradation of carbohydrate and other organic matter. The entire waste treatment plant thus involves following stages.

(i) Separation of fibrous matter i.e. large particles by screening.
(ii) Removal of oil and grease.
(iii) Impounding in large tank for anaerobic digestion.
(iv) Aerobic digestion for bio-oxidation.

4.3. The waste water flowing through channel is initially passed through a small pit fitted with stationary screens for eliminating oil and greasy material and large fibrous matter in suspension. The water then flows into an equalisation tank where lime is added to neutralise the acids and raise pH to 7.0. From the equalisation tank the water flows into a large tank with a residence time of 2-3 days wherein anaerobic bacterial decomposition of organic matter takes place and the suspended impurities as also the sludge settle down. To facilitate bacterial growth and their activity the nutrients like urea and superphosphate are added and initially some starter has to be added containing the bacteria. The overflow from anaerobic digestion pond is led to aeration tanks where surface aeration brings about bio oxidation of organic matter the resulting water being fit for letting into public streams.
4.4. At some factories the scheme of disposal involves only impounding water in a series of large ponds located away from plants, in which anaerobic digestion of organic matter is allowed to take place. Provided sufficient time is allowed for microbial action the water can be rendered suitable for irrigation but the ponds have to be sited in such a way that the odour nuisance does not pollute the inhabited areas. On the other hand the plants with mechanical aeration occupy considerably small area and pose no odour nuisance problem.

4.5. In one of the modern Indian factories the effluent water treatment plant consists of three clarifiers and three aeration units. The factory crushing around 1500 t cd is able to treat its waste water in this system and bring down B.O.D. from 800-1000 ppm to below 20 ppm. The total installed h.p for the units like aeraters and pumps is around 110.

4.6. In the system developed at Victoria Mills Queensland the factory waste water is first passed over DSM bar screen for removal of fibrous matter and then to oil separating tank. The water thereafter flows to primary pond where lime and nutrients are added for anaerobic degradation. The clear overflow from this stage enters secondary clarifier for aerobic digestion. Thus the stages involved are—

   (a) fibre and oil separation
   (b) primary pond
   (c) primary clarifier
   (d) secondary pond and
   (e) secondary clarifier from which water is discharged.

The sludge from primary clarifier is partially recycled to primary pond while part of the sludge from secondary clarifier is taken back into secondary pond. The discharged water had B.O.D. level of 26 ppm.

4.7. With proper house keeping the quality of waste water would not show much fluctuation and the B.O.D. level would be around 800-1000 ppm. Large variations in the B.O.D. load is caused only when overflows of juices or other sugarbearing material including final molasses take place in factory. Large fluctuations in the organic matter in the waste water is reflected in the nonuniformity in the composition of the discharge from effluent treatment plant, a situation which has to be avoided by rigid control on plant operation.

On cleaning day, large quantities [1000-1500 m$^3$ in 2500 tcd plant] of washings are discharged from the plant and these should preferably be impounded separately and allowed to flow into the first anaerobic treatment tank gradually after proper neutralisation.

5. CONDENSATES

The sugar cane brings with it around 67-70% water as shown by the following approximate composition—
(a) Brix or dissolved solids 15.5% cane
(b) Fibre 14% cane
(c) Brix free cane water 2.8% cane
(d) water 67.7% cane

Out of this water, the water leaving the sugar plant in different ways is categorised as under—

(i) make up water for boiler due to blow down
(ii) Vapours from evaporator and pans going to condenser.
(iii) Moisture in products leaving the process.

Water balance of modern sugar plant with vapour bleeding arrangement from pre-evaporator and other bodies of evaporator is presented in table 2.

Assuming 15° Bx and 100% mixed juice on cane received in the boiling house the condensates generated at juice heaters, evaporator and pans are used in the process in the following manners.

TABLE-2

(a) Mills 22-28% cane
(b) Boilers 3-5% cane
(c) Clarification—for chemicals 3% cane
(d) Clarification—for filter 3% cane
(e) Pans 5% cane
(f) Centrifugals and melting 5% cane
(g) Crystallisers Nil by recirculation of water in closed system
(h) Miscellaneous 5% cane

Total 46-54% cane

Out of the water used as imbibition on mills nearby half the quantity is returned to process in raw juice. A properly run plant can always save some condensate after meeting the process demands. In view of their high purity and high heat content the condensates have to be used in process avoiding use of cold water and thus proper conservation of condensates and control on their use assume special significance from the energy conservation angle. Optimum utilisation and conservations of condensates call for following measures—

1. Proper storage of condensates in tanks, attention to insulation of condensate pipes
and tanks and avoiding condensate flow into drains are essential prerequisites of condensate conservation.

2. On mills only hot condensates should be used for inhibition without admixture with cold water.

3. (a) a boiler blowdowns should be just sufficient to maintain the level of dissolved solids in boiler water within the prescribed limits.

(b) In factories quite often the feed water tank overflows into gutter due to continuous addition of make up water—which is mostly condenate from second body of evaporator. The wastage can be avoided by level controller installation and regulation of make up water on the basis of level in the feed tank.

4. (a) Pans: water used in the pan boiling should be metered and recorded for controlling use of water. This measure is closely related to steam economy in process.

(b) Rigid control needs to be exercised on dilution of molasses for conditioning the feed to pans and molasses conditioners should be installed with proper control on brix of molasses feed to pans.
REFERENCES

TABLE-1

Cold water utilisation

1. A Plant running-crushing rate about 105 - 120t/hr.

(a) Water which can be recycled

(i) Mill turbine 23-32 K litres/hr.
(ii) Mill bearings 14-21 K litres/hr.
(iii) Turbogenerator 23-32 K litres/hr.

(b) Water which being warm can be discharged into condenser water cooling system

(i) Sulphur burner 6-8 K litres/hr.
(ii) Crystallisers 14-16 K litres/hr.

(c) Water which can be partially circulated

(ii) miscellaneous pumps for gland cooling 5-7 K litres/hr.

(d) Water for gland cooling of some hot liquor pumps, cleaning and miscellaneous purposes to be let out as waste water 27-36 K litres/hr.

Total cold water required 112 - 152 K litres/hr.

(e) Water consumed on cleaning day 1200 - 1500 K litres.

(f) Water required for displacement of part of spray water 700-1000 K litres.
TABLE-2A
WATER BALANCE IN PROCESS (WITH ELABORATE VAPOUR BLEEDING)

(A) Water in cane 67.5 cane

(B) (i) Water in bagasse 13.4% cane

(ii) Water in filtercake 2.6% cane

(iii) Water in molasses 0.6% cane

Total water in products 16.6% cane

(C) (i) Water for boilers 5.0 cane

(ii) Water going in evaporator vapour 9.0% cane

(iii) Water in pan vapours 22.0% cane

(iv) Water for cleaning and miscellaneous purposes 5.0% cane

Total water 41.0% cane

B + C = 16.6 + 41.0 = 57.6

A - (B + C) = 67.5-57.6 = 9.9

Surplus water from Sugarcane = 9.9

TABLE-2B
WATER BALANCE IN PROCESSING SUGAR CANE

1. Water in cane 67.5
2. Water in bagasse 13.4
3. Water in filter cake 2.6
4. Water in molasses 0.6
5. Water going from evaporator 9.0
6. Water going from pans 22.00
7. Water for cleaning and miscellaneous 5.00

Total 52.6
TABLE-3
STANDARDS FOR DISCHARGE OF EFFLUENTS INTO IRRIGATION STREAMS

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>pH</td>
<td>5.5-9.0</td>
</tr>
<tr>
<td>2</td>
<td>Dissolved solids</td>
<td>2100 mgm/litres</td>
</tr>
<tr>
<td>3</td>
<td>Suspended solids</td>
<td>200 mgm/litres</td>
</tr>
<tr>
<td>4</td>
<td>Oil &amp; grease</td>
<td>10 mgm/litres</td>
</tr>
<tr>
<td>5</td>
<td>B.O.D.</td>
<td>100 mgm/litres</td>
</tr>
<tr>
<td>6</td>
<td>Sodium</td>
<td>60 mgm/litres</td>
</tr>
<tr>
<td>7</td>
<td>Chloride</td>
<td>600 mgm/litres</td>
</tr>
<tr>
<td>8</td>
<td>Sulphate</td>
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</tr>
</tbody>
</table>
16. TECHNICAL CONTROL IN SUGAR MANUFACTURE

PART-I

1. Technical control in the process of sugar manufacture is aimed at attaining highest possible efficiencies and recovering maximum sugar from the raw material which exhibits, varying compositions from period to period as well as from field to field in a crushing campaign, while at the same time maintaining the desired rate of production. Control of the process encompasses wide areas right from receipt of cane to storage of sugar and as such various operations involved, need careful observations and supervision in as much as the fall in efficiency or productivity at any station would adversely affect the overall performance of the plant to the detriment of the overall economy of the organisation. The main task of the technologists engaged in the process operation is thus to ensure effective technical control employing the systems evolved in the past for achieving the ultimate object of reducing sugar losses and cost of production in the manufacturing process.

2. TYPE OF CONTROL

In the present context, the term technical control denotes two types of process control viz.—

(a) operational control at different stations and

(b) chemical control.

Whereas the former is assigned to the technologists working at different levels in the factory, the latter task is the responsibility of laboratory section. However, since the operating staff is also guided by the data produced in the laboratory, the latter has to play key role in the entire scheme of things. The factory working staff controls operations in respect of the various parameters such as quantities, rate of flow of materials, temperatures, pressures, pH etc. whereas the chemical control depends on the records maintained in the factory along with the analytical data obtained. Thus interdependence of one on the other being beyond any doubt, close coordination of laboratory with the factory technologists assumes special importance for efficient organisation of the plant operation. Against this background it is necessary to go into the entire system of control, beginning with the operational control at different stations.

3. MILLING

3.1. In the process of sugar manufacture from sugarcane two major sources of unavoidable losses
are in milling and the final stage of crystallisation, commonly termed in the systems of technical accounting as bagasse loss and molasses loss respectively. Whereas the sugar lost in molasses can be gainfully utilised for production of chemicals like ethanol etc. the sugar lost in bagasse is irretrievably lost in the sense that it is burnt in boiler furnaces. Improving efficiency in the extraction of juice from cane has thus justifiably engaged constant attention of the technologists and research workers and as a result, great strides have been made in achieving high extraction by adopting various techniques such as—

(a) diffusion,

(b) high degrees of preparation,

(c) high imbibition etc. in the last two decades.

The aims of the system of chemical control at milling station are

(a) to collect and disseminate data for the benefit of milling technologists, to enable them to understand the weaknesses and flaws in working and devise ways and means for reducing sugar loss in bagasse,

(b) to collect, data, analyse the same and present the same in the form of reports incorporating statistics relating to working. It is necessary to emphasise that in the absence of fool-proof system of technical control, efforts to improve efficiency and reduce sugar loss will be mostly fruitless.

3.2. Basis of control—The system of technical accounting is essentially based on estimations of—

(a) quantities and

(b) analyses of various products in mill house.

The analyses of juices, cane, bagasse etc. to be really useful have a great deal to do with correct mode of sampling. The quantities involved in milling control are cane, mixed juice, water and bagasse, the last one being determined from the basic equation that cane plus imbibition water is equal to mixed juice plus bagasse. The analyses of primary juice, mixed juice and last expressed juice as also the bagasse at regular intervals provides the basic data for the technical control of the mill operation.

4. OPERATIONAL EFFICIENCIES

The milling efficiency is indicated by reduced mill extraction and whole reduced extraction as per the standard system of chemical control, and needless to state is indicative of the performance of the entire process of juice extraction. Every unit weight of fibre is inevitably going to take away some sugar with it from the extraction process and the efficiency relates to this loss reduced to certain standard figure of fibre in cane. However, the efficiency figures are calculated for day's operation and for periodical operations while the operating technologists are interested in the fluctuations in operations as reflected in the hourly or two hourly analyses which call for more data relating to mill working. Moreover apart from mill extraction and reduced mill extraction
data relating to Primary extraction is equally important in as much as the overall performance is dependent to a large extent on this figure. Similarly the extent of cane preparation which determines the primary extraction as indicated by preparation index is of utmost importance to mill engineers. The undiluted juice lost in bagasse percent fibre was adopted in Java Sugar Industry for judging mill performance and is adopted in the international system of chemical control.

Besides above the pol and moisture content of bagasse periodically determined (once in 2 or 4 hrs. usually) serve for immediate guidance of the mill engineers.

5.

5.1. The system of chemical control adopted by the Indian sugar factories based mainly on I.S.S.C.T. recommendations is per se extremely useful and by far the best under the circumstances. Nevertheless it suffers from some inadequacies as discussed below—

5.2. The basic equation that cane + water = bagasse + mixed juice, which helps us derive inferentially the weight of bagasse is true only if weight of cane as fed to mill and that of mixed juice are correct and the imbibition water does not undergo any loss of weight on being sprayed at mills. In actual practice it has been found that the cane undergoes some loss in weight due to driage while the hot imbibition water suffers loss due to evaporation cm being sprayed on bagasse after it is passed through meter. Similarly actual juice weight may also be more than recorded since it is weighed after some loss has taken place due to evaporation. The higher the temperature of imbibition water the greater would be the loss due to evaporation. The net result of these factors would be reduction in bagasse by 2% or so. It is significant to note that fibre in cane is determined from bagasse.

5.3. Any water from journal bearings or unweighed water used for washings of mills etc. mixing with juice in the mill gutters is bound to cause errors in the control system and lead to lower weight of bagasse estimated inferentially. It is common in sugar mills to wash mills with hot water and quite often this water is not metered or weighed; similarly cooling water from bearings many times flows into mill gutters, which is certainly avoidable.

5.4. Measuring water for imbibition and computing weight by applying factor of density is practised normally and if the meters are designed for high degree of accuracy the method is fairly reliable. However, if the water is measured in tanks as followed in some factories, with the number of tanks noted by operator, accuracy and reliability both suffer. This practice is to be discouraged.

6. Following steps have to be taken for arriving at the correct weights of the above materials viz., juice, water and bagasse—

(i) Weight of bagasse should be determined directly as per practice adopted in some factories in Hawaii by installing suitable machines capable of weighing accurately flow of bagasse on conveyer and intergrating the weights. This is a long felt need
which merits serious attention of research workers. Even accuracy of 0.5% in weight can be tolerated since this would be less than the errors in the present systems followed by us.

(ii) So long as bagasse weight is estimated inferentially it is imperative to pay greater attention to weights of cane, juice and imbibition water. Water should as far as possible be weighed automatically and in the absence of weighing equipment metering should be preferred, provided the meters are designed for a high degree of accuracy. Frequent calibration of juice weighing scales and imbibition water meters can eliminate to a large extent the errors in accounting.

(iii) No unaccounted water should be allowed to be mixed with juice in mill gutters. Even washing of mills can be managed with hot water passing through the imbibition meter. Thus this source of error is controllable.

(iv) Mixed juice weighing scales of the present design based on mechanical operation, counterweights, levers, pivots etc. have severe limitations from the point of view of accuracy and need to be replaced by automatic weighing machines with greater degree of accuracy. Servo balance Toledo scales, Foxboro weighing machines are reported to be more reliable, the last one working on air pressure. Servo balance scale is reported to give an accuracy of 0.1%.³

(v) As regards cane weighment, the existing scales should be equipped with mechanism for giving printed weights. However it is worthwhile examining the desirability of developing electronic systems of weighing with digital indicators. Moreover the time lag between weighment and feeding to carrier has to be minimised for accuracy of chemical control.

7. SAMPLING AND ANALYSES

Under Indian conditions the sampling of cane is not important in the absence of any systems of payment of cane on quality basis and with the system of direct weighment of cane. However sampling of various juices and bagasse mostly manually done, leaves lot of scope for improvement in the interest of efficient technical control. Primary juice is important for calculating—

(a) undiluted juice lost in bagasse per cent fibre and

(b) primary extraction.

Similarly last expressed juice analyses give us fibre % bagasse and ultimately the fibre % cane. It is necessary to introduce continuous sampling of these two juices in place of the manual sampling done by unskilled workers. Since composition of these juices changes frequently with quality of cane and variations in mill operations, batch sampling even if practised at regular intervals cannot be as reliable as the continuous sampling method.

As for bagasse, since continuous sampling is impracticable, samples have to be collected from the entire width of bagasse blanket soon after it emerges from last mill at regular intervals.
The frequency of sample collection and analyses are of equal importance for obtaining accurate representative data. The juices have to be analysed once in two hours whereas the bagasse analysis must be carried out once every hour as against the practice of analysing the bagasse samples once in four hours.

Preservation of juice samples by addition of mercuric chloride is quite common. It is desirable to use solution of mercuric chloride in ethanol as in solid forms it dissolves with difficulty in juices. New preservatives which are at least as effective as the mercuric chloride, but will be easily dispersed in juices need to be developed. Preservatives are to be added after sampling of juice commences.

8. ANALYSIS

8.1. As stated earlier frequency of analysis of juices and bagasse along with correct sampling procedures have a great bearing on the reliability of the system of chemical control followed in a particular factory. Two hourly analyses of mill juices would pose no problems, however more number of bagasse analyses per shift would call for quicker methods of determination of pol and moisture of bagasse. Use of disintegrator method or rapi-pol extractor for estimation of bagasse pol widely adopted in the sugar mills of Australia, South Africa etc. being a rapid and reliable method will help to increase the number of bagasse analyses and will ensure greater accuracy in the bagasse and cane pol figures. The discrepancies observed in chemical control and in particular, the variations in pol in cane with imbibition can be traced to the inaccurate bagasse pol which does not represent the pol content of the entire lot of bagasse.

Preparation index of the cane before its entry in the first mill must be determined as a matter of routine once per shift or at least once in a day in view of the importance of cane preparation and its profound influence on the milling efficiency. It is desirable to incorporate the figures for preparation index and primary extraction in the daily manufacturing reports for the guidance of the mill technologist.

8.2. Brix Curves—Brixes of juices from discharge rollers of all the mills are plotted against the serial number of mills, care being taken to see that juices are properly sampled under normal operating conditions of mill and correspond to the same bagasse throughout the milling train. The curves thus drawn serve to indicate drawbacks of particular mills or mill since the graph must show smooth downward trend in brixes from the first to last mill. This method of brix curves has to be followed frequently as it serves to guide the mill engineer in judging the efficacy of the settings and locating faults in operation. The interpretation of the graphs of mill brixes is based on the smoothness of curves rather than on comparison with model graphs based on ideal brixes of juices from different mills, calculated with the help of standard formulae. A sudden kink or a deviation from smoothness of the curve at a particular mill is indicative of malfunctioning of the previous mill.
9. IMBIBITION

There exists a high correlation between brix of last expressed juice and the mill extraction as shown by the statistical studies conducted by D.P. Kulkarni which leads to the conclusion that—

(a) brix of last expressed juice should be continuously measured and displayed for adjusting imbibition,

(b) it is possible to install controller for imbibition water, which will regulate the water valve on the basis of signals received from brix indicator of the last expressed juice.

This automation will ensure uniformity in the application of imbibition water quantity and result in reduction of sugar loss in bagasse.

10. MILL SANITATION

10.1. Since the cane juice provides ideal media for the growth of innumerable types of microorganisms, it is pertinent to expect deterioration of cane juice in its passage through the milling process resulting in loss of sugars. The quantum of sugar loss in mills due to microbial action does not figure in the manufacturing reports, nor is it recorded. Staleness of cane and warm atmosphere are conducive to this microbiological activity. Several pockets of fermentation are formed in mill gutters, juice strainers, bagasse carriers, juice tanks etc., wherever bagasse or juice stagnates. Yeast and invertase convert sucrose into reducing sugars, while lactic acid bacteria generate acids thereby increasing acidity in juice. Leuconostoc bacteria form gums at the expense of sugar. In consequence, the microbial growth if not checked effectively increases reducing sugars, acids and nonsugar matter at the expense of sucrose and reducing sugars. Nonsugars thus formed not only reduce the recoverable sugar but also create problems in the boiling house operation.

Drop in purity from primary juice to mixed juice is a rough indication of the microbiological activity in milling, which varies from 1.7 to 2.7 units in different factories and in different periods of the crushing campaign. The extent of loss in sugar can be assessed by determining the acidity and reducing sugar/brix ratio in primary and mixed juices. This method is very useful for comparative studies on efficacy of sanitation measures, though it does not provide absolute values for judging the sanitary conditions. Various studies conducted indicate the loss of sugar in mills due to microbial activity to vary from 0.1 - 0.2% cane.

This loss though not completely avoidable can be controlled and minimised, to a considerable extent by maintaining sanitary conditions around the mills for which—

(a) steaming

(b) spray of bactericides are the common measures advocated.

Steaming of the pockets of fermentation, carriers etc. can control the microbial activities to the extent of 60% only in the absence of sanitation agents as shown by Chen.
This shows that the use of disinfectants is a 'must' and coupled with steaming and hot water washing can effectively check the growth and activity of micro-organisms. Extensive studies carried out recently in India and other countries have shown that the quaternary ammonium compounds are far more effective as biocides in controlling the growth and activity of yeasts and different types of bacteria than the conventional halogen based chemicals.\(^7\)

11. SPECIAL EQUIPMENT AND INSTRUMENTS

11.1. The control laboratory has to be equipped suitably with special equipment like high speed disintegrator for rapid determination of bagasse pol and air ovens with air circulation for moisture in bagasse. New instruments for rapid determination of bagasse moisture employing infra-red heating or electronic devices need to be developed for the benefit of the sugar mills. As far as the operation side is concerned continuous indicating instrument has to be developed for indicating moisture of bagasse flowing out of the last mill. Likewise at the last mill, brix indicator for brix of last expressed juice will serve the operating staff in regard to the quantity of imbibition water to be applied at the mill. Continuous indications will be of great advantage to mills in maintaining uniform conditions in the process of milling.

12. CLARIFICATION

12.1. At the clarification station the main parameters of operational control are pH, temperature and brixes. pH control at clarification can be automated to a limited extent when lime dosing is regulated by pH controller.\(^8\) Perfect pH control would be achieved only when lime flow in proportion to juice flow is maintained and SO\(_2\) gas regulated on the basis of pH of treated juice. This system of complete automation in juice sulphitation has been introduced in Indian industry with good success. For this, juce flow stabilisers have also been installed.\(^8\text{a}\)

Of equal importance is the proportioning of phosphate doses to fulfil the requirement of efficient clarification, which can be automated without much difficulty. The technical staff has thus to ensure proper dosing of lime and phosphate in accordance with the predetermined quantities worked out in the laboratory experiments. With or without automation the control on dosing of lime and phosphate in proportion to the juice and final pH of treated juice has to be strict, likewise the temperatures of untreated juice as also treated juice are required to be maintained at 70° -- 75°C and 100° - 105°C respectively. It is necessary to maintain proper records of doses of chemicals, temperature, pH and quantities of juice once per hour. pH should be necessarily estimated with the help of a pH meter, working with glass calomel electrode system. In a modern plant, the clarification section should be equipped with following instruments or meters which serve as control aids:

(i) Temperature gauges: for raw, treated and cl. juce and SO\(_2\) gas before and after cooler.
(ii) pH controller for juice treatment.
(iii) flow indicator for raw-juice.
(iv) water meter for wash water at vacuum filter.

The quantity of bagacillo used at vacuum filter needs to be checked off and on for maintaining proper ratio of bagacillo to mud, so that the effective screening area on bagasse conveyor can be adjusted.

13. EVAPORATOR

13.1. The main function of this unit is to concentrate the clear juice to 60° - 65° Bx, which is closely linked with the steam consumption of the process. Continuous recording and indication of brix of syrup would serve as a useful tool in the hands of supervisory staff. However continuous brix measurement has not been developed in our industry to the point of being universally adopted. Nevertheless frequent checking of brix of syrup is possible.

The temperature and pressure or vacuum of each body have to be closely watched from first body calandria to last body. Level regulators of liquid in each body introduced in some factories help attain maximum rate of evaporation from each body. With constant pressure of exhaust steam fed to calandria of first body and regulation of levels of all the bodies of evaporator, the rate of evaporation is well under control, the final vacuum of last body remaining unaltered.

As for syrup sulphitation the main parameter of operation is the pH of outgoing syrup.

14. CRYSTALLISATION

14.1. Pans—Temperature gauges have to be fitted to all pans and pan supply tanks. Similarly, apart from vacuum and pressure gauges, the pans have to be equipped with conductivity instruments which can serve for control of pan boiling. The day is not far off when we shall control boiling automatically, either based on mobility principle or on the basis of conductivity instruments, both of which help maintain the desired concentration of mother liquor for growth of sugar crystals in the pan. With or without automation, the 'B' & 'C' boiling can be carried out with the full use of conductivity instruments in view of the more or less constant purities of mother liquor. 'C' pans provided with circulators have the additional advantage that the circulator load in amperes can give good indication of the high concentration during final tightening up phase. It has been found that right from graining upto final tightening, conductivity readings provide reliable guidance for pan boiler who can conduct the entire operation with the help of predetermined conductivity data.

The main aim of pan boiling is to crystallise out maximum sugar from syrup, making maximum use of the capacity installed. Thus scientific pan boiling control would call for—
(a) production of desired size sugar grains,
(b) reduction in molasses purity in the pan,
(c) use of minimum water and steam for pan boiling,
(d) making maximum use of pan capacity by reduction in non-boiling down time,
(e) reducing boiling time of each strike,
(f) reduction of recirculation of sugars and non-sugars.

It must be emphasised that 50-60% of the total loss of sugar in cane sugar manufacture is accounted for at the crystallisation stage and pan boiling is the most important function, requiring skill, judgement and scientific outlook. The technologist has to oversee that the above mentioned factors are duly taken care of at pan station. Pan floor records should contain the history of each strike and graphs should be drawn showing position of each pan, in relation to time.

Automation of following operations, which would not involve much investment should be adopted in sugar mills—

(i) maintenance of constant pressure of vapour or steam for boiling,
(ii) conditioning of A Heavy, B Heavy and C light molasses.

Besides, the water used in pans should be metered and recorded per shift.

14.2. Crystallisers—The crystallisers serve to complete the work of exhaustion of mother liquor besides working as receiving vessels. Cooling of all massecuites improves exhaustion and temperatures of all massecuites before their purging commences, have to be noted. In low grade strikes particularly, not only cooling to the desired temperature (40°C) but the rate of cooling also needs to be carefully mentioned so as to achieve maximum exhaustion as well as for avoidance of false grain formation occasioned by sudden cooling. As regards reheating of 'C' massecuite it has now been widely accepted that the redissolution of crystals during heating can be avoided by reheating the massecuites in stationary coil reheater. It is important in this connection to instal a closed vessel with cold and hot water arrangement, along with a pump for cooling of 'C' massecuites since the temperature of cooling water should not be tower than 5° - 7°C below that of massecuite to be cooled.

14.3. Centrifugals—Function of centrifugals is to separate sugar crystals from mother liquor and lack of control at this station can bring about recirculation of sugars and non-sugars with deleterious effect on sugar loss in process. Thus it is imperative to ensure highest possible purity of sugars in 'A', 'B' and 'C' curing with minimum use of water so as to bring down recirculation of non-sugars and sugar respectively. It is desirable to provide flow meter for centrifugal station to control the use of water at every stage. Likewise me temperatures of water and steam have to be noted at regular intervals.

Flow of final molasses per hour serves to indicate the health of the process in as much as the outflow of sugar is closely linked with the same and should be recorded regularly.
In general, at the crystalliser station, history of each strike from start to end of curing, throws light on—

(a) the time cycle of each strike and

(b) exhaustion obtained.

This record should be maintained so as to detect the flaws, if any, at any station as also to improve the performance. Records giving operational details like temperatures, brixes purities etc. for all strikes, if studied carefully, throw light on the weaknesses of the system and the human errors which can be rectified in time.

15. SUGAR QUALITY

As is well known, bigger grain sugar of even size fetches higher price and sieve analysis of sugar bagged, helps to understand the quality of grain being marketed, while colour can be determined by visual comparison with the standards. Every factory must have sieve tester with sieves as per I.S.I. specifications.

The sugar being reprocessed per shift is reboiled and the quantum of sugar to be put back for reprocessing has to be noted and controlled since reboiling results in some unavoidable loss. This holds true as much for the sugar from sugarhouse, as for the sugar damaged in godown where improper and unscientific storage results in sugar absorbing moisture or bags getting damaged resulting in physical loss.

16. RECORDS

Maintenance of records providing data relating to operational conditions at all stations is of vital importance as the data thus collected reveals the complete picture of systems connected with the entire process operation from crushing to bagging, and the technologists must ensure proper recording and also study the same often. Record forms should be devised taking into account the process requirements as also the equipment installed, and trained personnel have to be charged with the responsibility of entering the data. In view of the fact that in the absence of correct data, the technical control becomes unscientific and unreliable, faithful filling of records pertaining to each station assumes special significance in entire process control work.
PART-II

ROLE OF LABORATORY

1. Every sugar mill necessarily has a laboratory attached to it which is entrusted with the task of carrying out various analyses and preparing manufacturing reports. The laboratory has, in fact, to do a lot if it is to serve for efficient control of the factory operation. Besides collection of data for the various manufacturing reports the laboratory must—

(i) conduct special analyses for various stations,

(ii) carry out investigational work pertaining to problems faced in operations in process,

(iii) assist in development of cane Agriculture on Scientific lines.

The above areas are usually neglected and work pertaining to the same will help the factory technologists in their efforts for improving plant performance.

2. CANE QUALITY

This is an area in which a close coordination of Agricultural Department and the laboratory is essential. Special functions which have to be assigned to laboratory in this connection are as follows—

(a) Tests have to be conducted on experimental plots with special treatment. This may even require full scale factory tests.

(b) Refractometric survey—The refractometric tests of standing cane should be carried out for one month prior to commencement of cane crushing campaign and should be continued till November end, in which participation of chemists in laboratory along with Agriculture staff would be necessary. This is to be accompanied by laboratory tests of cane samples for estimation of purity. Importance of refractometric survey for improving cane quality need not be elaborated.

(c) Area-wise factory tests of cane should be conducted in the season to assess the cane quality aspects.

(d) Extraneous matter in cane is harmful as it leads to higher avoidable losses in process and it is necessary to estimate the same as a matter of routine every day so that the harvesting operation can be improved for reducing the same.\(^\text{11}\)

(e) Sugar factory laboratories can undertake soil analysis in the off-season.

3. MILLS

(a) The preparatory index of cane being fed to mills should be found out every day as a matter of routine in view of its influence on milling efficiency. This will serve to guide the mill technologists as regards the effectiveness of the preparatory devices.
(b) Brix curves have to be drawn occasionally for assessing the operating efficiency of each unit in the milling tandem. The mill engineer adjusts the mill settings on the basis of brix curves drawn by the laboratory.

(c) High primary extraction contributes to a considerable extent to the overall efficiency of the milling efficiency and should be determined and recorded regularly. For this, careful sampling and analysis of primary and secondary juices are necessary.

4. CLARIFICATION

Apart from routine check up of the operation at this station with respect to pH, brixes etc. special analyses have to be conducted at this station as under—

(a) R.S. % pol of raw-juice, clear-juice and syrup should be determined as a matter of routine on composited samples as it throws light on inversion in clarification or destruction of reducing sugars.

(b) CaO and P₂O₅ in raw and clear juice should be estimated often.

(c) Control on quality of lime, phosphoric acid etc. rests with the laboratory in so far as the quality of chemicals plays vital role in the clarification process.

(d) Experiments have to be conducted in the laboratory on determination of optimum doses of lime and phosphoric acid as well as a variations in initial raw juice heating, in order to arrive at the proper doses for obtaining maximum elimination of non-sugars as also good settling rate of mud, particularly during periods of 'mud trouble'. The efficiency of settling aids should also be tested in the laboratory before arriving at the proper dose.

Likewise, proper mode of liming and sulphitation i.e. either preliming or presulphitation can be decided on the basis of laboratory scale experiments. It is necessary to equip laboratory with S0₂ gas cylinder or provide connection of S0₂ from factory on clarification station for conducting these experiments.

(e) Sucrose purities of raw juice, molasses and clear-juice are to be determined often in view of their influence of chemical control.¹²

5. EVAPORATOR

The effective utilisation of heating surfaces of different bodies can be assessed only by finding out brixes of syrup or juice leaving each body and the juice input. This data throws light on working of each body and thereby helps factory staff to understand the weaknesses in the system.

Scales in different bodies should be collected by inserting M.S. rods in the tubes and periodwise scales collected, which can be analysed in details in the off-season.

In the vapour cell or first body, maintaining high pressure of exhaust steam raises the rate of evaporation, and thereby helps in supplying adequate vapours for pans and juice
heaters. However inversion can result from contact with heat with resultant sucrose loss, which has to be avoided in any case. Thus for deciding the optimum steam pressure inversion studies have to be conducted to arrive at safe maximum pressure which will not bring about destruction of sugars.

The chemical composition of solutions after boil out of the evaporator bodies, gives an idea of actual consumption of chemicals in the boiling operation for dissolving part of the scale. This work can be done after cleaning day.

6. CRYSTALLISATION

Apart from the routine checking of purities of different massecuites and molasses, the exhaustion in final boiling needs careful watch and in this area, the laboratory can play useful role. 'Nutsch' samples of molasses from 'C' or final massecuite at the time of dropping and after cooling have to be regularly analysed so as to get a clear picture of exhaustion at different stages. Moreover, the laboratory can assist the factory technologists in arriving at the optimum quantity of seed to be used in the form of fine sugar slurry by counting the grains with the help of microscope. In accordance with the standard practice of seeding the 'C' pan or 'B' pan for graining, it is imperative to standardise the procedure with respect to preparation of slurry and the quantum thereof being fed to pan. This is possible only if the total quantity of grains per cu.m. of strike is fixed.

White sugar to be marketed should be analysed for grain size with the help of mechanical sieving as a matter of routine.

7. SPECIAL ANALYSES

(a) Effluent quality control has become mandatory and the factory must determine the B.O.D., pH and suspended solids daily, besides finding out detailed composition of the same once per week, to check whether the same conforms to the values stipulated by the pollution control board.

(b) Boiler water and feed water quality control are the responsibility of the factory laboratory and apart from detailed analysis of the same once per day pH and dissolved solids must be determined once per shift.

(c) Sugar tests of condensates, feed water, condenser water and factory effluents are a 'must' for routine control.

(d) Dry and wet bulb temperatures, which give relative humidity of atmosphere are useful from the point of view of knowing the performance of the spray cooling system as well as the storage of sugar in godowns. Thus daily recording of these temperatures and humidity are very helpful.

(e) Final molasses should be composited and fortnightly samples preserved during the seasons, to be analysed in details in the offseason. These analyses provide valuable
data with respect to changes in the composition of cane as also the exhaustion potential of molasses in relation to periods and seasons.

(f) Experiments have to be carried out in laboratory on determining optimum temperatures and doses of the chemicals for the sulphitation process once in every month since changes in the composition occasioned by levels of maturity, call for variations in the methods in treatment as for instance juices from immature and mature cane will need different doses of phosphate and lime for good clarification.

(g) At mills, the microbiological activity can bring about destruction of sugar in as much as raw cane juice offers an ideal medium for microbial growth. Rough indication of sanitation at mills is provided by the purity drop from primary juice to mixed juice. However careful studies have revealed that the drop in pH and increase in reducing sugar percent and R.S./pol & R.S./brix/ratio are more reliable, for this purpose. These have to be determined from time to time with a view to assessing the efficacy of cleaning and use of biocides for checking microbial growth.

(h) The boiler flue gas analysis for CO$_2$ & O$_2$ throws light on the nature of combustion of fuel and instruments provided at boilers are supposed to indicate the same. However, it is necessary to determine these by flue gas analyser often, to check the accuracy of instrument reading, if the same are in working order or in the absence of the same as a matter of routine.

8. RECORDS

Apart from preparing regular manufacturing reports the laboratory should also maintain regular records of the special analyses enlisted above. Likewise records of steam utilised and special problems faced in the factory operation need to be maintained. It must be emphasised that the records of work done in the laboratory over some period become very valuable in the long run in that they serve to guide the technical staff and the management from time to time in respect of problems faced in working and measures adopted to overcome the same.
REFERENCES

8. Seminar on Automation held at D.S.I. Manjari 1985
   also Maharashtra Sugar August 1985.
17. UTILISATION OF BY-PRODUCTS OF CANE SUGAR MANUFACTURE

1. The process of sugar manufacture from sugar cane generates to following products besides sugar—

   (a) bagasse -&gt; 24-30% cane
   (b) Molasses -&gt; 3.5-4.5% cane
   (c) Filter cake -&gt; 3.5-4% cane

   In the early stage of the industry disposal of these products could be accomplished by burning the bagasse in boiler furnaces, using filter cake in the fields but the disposal of molasses posed problems and as such these were considered as undesirable industrial wastes creating environmental disturbance. Many factories had to encounter difficulties in disposing of the surplus bagasse. In the past 5-6 decades however, thanks to the sustained efforts of research workers and technologists considerable progress has been achieved in the proper use of these by-products for manufacture of number of items of industrial significance. Particularly in the last two decades profitable utilisation of the by-products of sugar manufacture assumed great importance in view of vast potential they offer in the manufacture of various useful products like paper, ethyl alcohol etc. besides the generation of electricity. In brief the major consideration weighing with the industry for judicious use of these waste products and the advantages therefrom can be summed up as under—

   (a) It has become necessary to make the best use of the biomass generated in the field in view of the energy crisis and raw material shortage.

   (b) Environmental protection requires no organic or inorganic materials to pollute the air or water.

   (c) Conversion of by-products into useful chemicals and products will impart greater financial stability to the main industry.

2. BAGASSE

2.1. Bagasse which is the residue of the sugarcane, emerging from the grinding operation on extraction of juice has following composition

   (i) Water 45-50%

   (ii) Dissolved solids including sugar 2.5-4%.
(iii) Fibre 45-50%.

The water insoluble portion of bagasse is the fibre composed of cellulose, pentosans, lignin, and some mineral matter. The percentages of major components of dry bagasse vary widely in different countries as reported in literature and the averages given by Paturau \(^1\) are as under:

- (i) Cellulose: 36.0%
- (ii) Pentosans: 26.0%
- (iii) Lignin: 20.0%
- (iv) Ash: 2.2%

The fibre portion of bagasse can be classified into two major categories according to the structural difference in tissues:

(a) True fibre composed of tough portion of rind and vascular tissues.

(b) Pith which is soft in nature consisting of thin wall cells of the inner part of the cane. It is the true fibre part of bagasse which is of interest in paper and board manufacture since:

(a) Length to diameter ratio of true fibre cells is 70 as against 5 for pith cells.\(^2\)

(b) On account of above, pulp from fibre possesses satisfactory strength and good property of felting. The pith portion with irregular shaped cells, possesses absorbant property and the pulp prepared therefrom lacks the desired strength for paper production. This renders it essential to separate pith from true fibre portion of bagasse whenever it is to be employed as raw material for paper or paper board manufacture.

2.2. Storage of bagasse—A well run modern cane sugar mill can save 3-5% of bagasse after meeting the requirement of boiler for running the plant. Thus a sugar factory handling 500-600 thousand tonnes cane per annum will save 20,000 - 25,000 t of mill wet bagasse with about 48-50% moisture and as the cane sugar mills run mostly for 5-8 months in a year it has to be stored properly for disposing it of as raw material for another bagasse based industries. Moreover, loose bagasse has very low density viz. 120 to 160 Kg/m\(^3\) and is inflamable which render it necessary to take special measures for proper storage. On account of the presence of sugar (2-4%) and high moisture, under action of microorganisms of different types like yeasts, fungi etc. fermentation takes place during storage with production of alcohol, acetic and other acids. Temperature rise can also occur in bagasse piles and all these reactions lead to weakening of the cellular tissues of bagasse fibre. Standard practice with factories is to bale and store the bagasse in stacks in the open for further use. Bales are formed in press usually of 300 x 300 x 600 mm size or even of bigger size. These bales are tied with steel wire.

In Trinidad it was observed that in bales of bagasse with 50% moisture temperature rose to 54\(^\circ\)C within 3 days and remained between 40\(^\circ\) - 50\(^\circ\)C for 45 days during which period water content dropped to 20\%.\(^3\)
The various preservatives like propionic acid, organic sulphur compounds have been found to be effective in checking the fermentation activity which causes deterioration of fibre.\textsuperscript{4}

In wet storage of bagasse biological liquor consisting mainly of lactic acid bacteria developed in dilute molasses is used. Dipped bagasse from mill is treated with this biological liquor and stored on concrete floor with arrangement to circulate the liquor by pumping over the pile.\textsuperscript{5} This system known as Ritter method is found effective.

Storage of depithed bagasse is preferred from the point of view of using it in paper and pulp industry.

2.3. **Separation of pith**—Separation of pith from true fibre can be accomplished by three methods—

(a) In humid depithing system bagasse as obtained from mill with around 50% moisture can be depithed.

(b) In dry depithing method, bagasse moisture has to be brought down.

(c) Wet depithing involves separation to be effected with bagasse suspension in water.

Suitability of a particular system is determined by the end product to be manufactured and sometimes a combination of two methods of depithing is adopted. Suitable machines have been developed to suit the requirement of particular process of pith separation which is considered absolutely essential for successful use of bagasse as raw material for paper and such other fibre based industries.

2.4.1. Commercial exploitation of bagasse as raw material for paper was tried out in the later half of nineteenth century in Louisiana, Brazil, Cuba, Java etc. but commercial success was achieved only in the past five decades and last two decades witnessed rapid strides in this area thanks mainly to the necessity of using renewable source of fibre for ever expanding paper and pulp industry and save forests.

2.4.2. **Paper and Pulp**—Manufacture of pulp and paper from bagasse involves treatment with alkali for elimination of undesirable constituents like lignin and pentosans.

The entire operation of paper mill employing bagasse as raw material involves following major steps—

(a) Depithing for separation of fibre

(b) Treatment of fibrous portion with dilute caustic soda at high temperature in digester.

(c) Separation of pulp from chemicals.

(d) bleaching.

(e) washing free of chemicals.

(f) dewatering

(g) passing through machines for felting, conversion into paper sheets and removal of water.
Different grades of paper are made from bagasse and in recent years even newsprint manufacture is receiving special attention with bagasse—based newsprint plants being established in different parts of the world including India. Modern paper plants have to be necessarily equipped with chemical recovery system so as to recover large part of the alkali and sodium salts introduced in the digestion process not only for economic reuse of these chemicals but also for avoiding environmental pollution since in the absence of chemical recovery units the sodium salts and other dissolved matter would have to be let into public streams or rivers. However the mini paper plants with capacity range of 20-30 TPD cannot install the recovery system for economic reasons and in view of the total investments involved in the complete recovery system paper unit capacity of new plants of 150-200 t pd. is considered to be economical.

2.5. Paper Board—Other types of packing material: Bagasse is considered proper raw material for corrugating board manufacture on account of its fibre structure and pentosan content which impart to it strength and rigidity. Depithed bagasse is cooked in digester in neutral sulphite liquor consisting of soda ash and sulphur. The resulting pulp is screened and sent to board mill.

In the manufacture of insulation board the bagasse after separation of pith is cooked in water in a digester. This is followed by sizing operation in which rosin, alum are added and the pulp sent to board forming machines. The boards are further treated with asphalt or paint and insecticides depending on the end use.

Bagasse based insulation board plant is operated in Louisiana since 1922 and these have been in operation in other sugarcane growing regions like Taiwan, Cuba etc.

In hardboard manufacture two methods are adopted viz. wet pressing and dry pressing the pressing being carried out in multi-opening presses heated by steam.

Particle boards which are manufactured from small pieces of lignocellulosic material like wood require the use of organic binding material or synthetic resins and pressure. Out of the three types of board produced by hot pressing the single-layer boards have the fibre particles distributed in homogeneous manner and their strength is determined mainly by the density. In the three layer board the mass of large particles forms the inner core while the two surface layers, are formed of smaller fibre particles. These are considered suitable for furniture. In the third type are graded density boards wherein the distribution of fibre particles is such that bigger size forms the central portion and particle size gradually decreases from centre to out layers. The strength of these boards lies between that of the above two types. The bagasse to be used in particle boards production is shredded, screened and dried to about 4% moisture before being screened again to eliminate the pith portion. For bagasse based particle boards urea, formaldehyde is used for bonding while wax is used as water repellent.

2.6. Use of pith—Pith which forms 35-40% portion of bagasse when separated from fibre has to be gainfully utilised. Pith contains more ash than fibres and can be used in the following manner—

(a) As fuel—Pith has somewhat lower calorific value than the whole bagasse on account
of higher ash content than the latter as also the tendency of soft particles to absorb moisture quickly and the pith containing 2-3% higher moisture than the entire bagasse.\(^9\) Pith can be burnt alone or along with coal or oil.

**(b) As cattle feed**—Pith can be used in preparation of cattle feed made from molasses, urea, oilcake and some common salt.

**(c) Poultry litter and agricultural mulch**—Being of organic origin and of low density bagasse can become a good bedding material for cattle or litter for poultry. Bagasse is dried in dryers, screened and baled before being used in poultry. In Agriculture, particularly in orchards and flower gardens bagasse can serve as mulch to minimise moisture loss from soil, for controlling weeds, soil erosion etc.

### 2.7.2. Miscellaneous uses of bagasse

Number of other products can be manufactured from bagasse on commercial scale. Few of these are described below—

**(a)** The lignin in bagasse forms the basis for production of plastics from bagasse for which separation of cellulosic fibre is essential and bagasse has to be digested by adopting—

1. Acid hydrolysis or 2. Water and aniline hydrolysis or 3. alkali. Products possessing good hardness, strength and high water as also heat resistance are manufactured\(^9\) from bagasse.

**(b)** Furfural—Furfural is an aldehyde produced from pentosans and serves as solvent in refining lubricants and for wood resin and can also be used in the manufacture of Nylon 6.6. With major percentage of Xylan (> 90%) in the pentosans (25-30%) of bagasse it is ideally suited as raw material for furfural plant. Acid hydrolysis of xylan converts it into xylose which after losing three molecules of water yields furfural according to equation

\[
C_5H_{10}O_5 \rightarrow C_5H_4O_2 + 2H_2O \text{ furfural}
\]

Furfural alcohol produced by hydrogenation of furfural is used in producing corrosion resistant and heat stable resins.

**(c)** a Cellulose or dissolving pulp i.e. the part of cellulose which is insoluble in 17.5% cold caustic soda solution can be produced from the cellulosic portion of bagasse

**(d)** a Cellulose is used in rayon and acetate fibre, plastic, explosives, lacquers etc. Commercial exploitation of bagasse for a cellulose manufacture has not yet been established.

**(d)** Xylitol—Pentosans in bagasse are mostly composed of polysaccharides Xylan and Araban. Xylan which is formed from over 40D - Xylopyranose molecules, on hydrolysis is decomposed to D Xylose, which has a sweet taste and is soluble in water and alcohol. Hydrogenation of Xylose under high pressure yields Xylitol \(n(C_5H_{12}O_5)\) which has the same sweetness as sucrose. It serves as a good substitute for sugar in the diet of a diabetic on account of its absorption in the human system without causing rise in glucose level in blood.\(^{10}\)
2.8. Lot of experimental work has been carried out on using bagasse for other purposes such as for concrete and preparation of active carbon. It is possible to convert the cellulose of bagasse into simple hexose i.e. glucose by the use of suitable enzyme and later produce protein from the sugar employing microbial fermentation.

2.9. **Use as source of additional power**—As at present most of the white sugar plants with the exception of a few factories are consuming a substantial portion of bagasse produced as fuel for generating steam and electricity. Since more than two decades the sugar mills in Hawaii have been producing surplus electric power by consuming the entire quantity of bagasse produced, to be used for agriculture. These factories, however have installed high pressure boilers (30-80 Kg/cm\(^2\) pressure) and turbines to suit the same whereby they are able to generate more electricity after meeting the process demands and use the same for agriculture and feed it to state grid. In India also this renewable source of fuel offers, vast potential for generation of over 400 M.W. surplus electric power which can be used by other industries and with the new trends in installation of 30-40 Kg/cm\(^2\) pressure boilers in sugar mills time is not far off to exploit this vast source for surplus energy generation after meeting industry's requirements. Essential pre-requisite for this is effecting maximum economy of energy consumption and saving as much bagasse as possible. Apart from adoption of steam and fuel economy measures it is essential to instal:

(a) boilers of pressure 30 and above Kg/cm\(^2\)

(b) turbogenerators to suit the above high pressures

(c) arrangements to supply surplus electric power to state grid or other industries.

Bagasse of sugar factories could be utilised for generation of surplus electricity in different ways such as—

(i) Installation of central power generating station which will receive surplus bagasse from group of factories, and will work throughout the year. The cost of baling, transport and storage of bagasse will however be a major cost factor.

(ii) Individual large plants handling 600-800 thousand tonnes cane p.a. can generate surplus power during the crushing season and feed it, to the state grid or to some other industries in the neighbourhood of cane sugar factory. Sale of electric power by sugar factories is a highly profitable proposition and will catch up fast in the near future in the developing countries.

2.10. **Bagasse ash**—The ash from bagasse fired boilers produced at the rate of around 0.4 - 0.5% cane is usually dumped in fields or in fallow lands. With its high potassium content (5-10%) and phosphate content its use as fertiliser has been reported to give encouraging results.\(^{11}\) This ash contains high silica of 70-75% and has the potential of being used in glass manufacture.
3. FILTER CAKE

3.1. Filter cake produced at the juice clarification station by rotary vacuum filters to the extent of 3.2-4% on cane has following approximate composition—

(0 Moisture \(\rightarrow\) 75-80%, Sugar \(\rightarrow\) 1-3%, Fibre 5-10%.

Filter cake contains most of inorganic salts like sulphites, phosphates precipitated during clarification and serves as a good fertiliser in the fields. Most of the fertiliser value of filter cake is attributed to its phosphate content and composting the cake for using it in fields is a common practice in India. Moreover composted filter mud adds humus to the soil on account of the organic matter and dewaxed cake is reported to produce good results in crop production.

3.2. Sugar cane wax—Out of the total coating (about 0.12%) of wax and lipids on the cane stalk, about 40% is extracted in cane juice which during clarification, is occluded by the inorganic salts formed and finds, its way in the filtercake. The total crude wax obtained varies from 6-9.5% in dry filter cake depending on the solvent employed for extracting the same. The process of recovering this wax is the solvent extraction system well established in extracting oils from oilcakes. The dewaxed cake can be a very good manure in the fields.

The crude wax consisting of esters, fatty acids, alcohols and hydrocarbons contains about 50-60% hard portion the remaining being soft lipids. The hard wax has a melting point of 75°-80°C and can be used as a substitute for carnauba wax in industries like polish, carbon paper manufacture etc. The soft part can yield sterols and fatty acids, besides, being useful for fruit coating and preservation.

The soft fatty fraction can be separated from crude wax by cold acetone treatment or absolute alcohol as shown by work at Ravalgaon. Extraction of fatty portion from filtercake by cold petroleum solvent followed by high temperature treatment with the same solvent yield separately soft fatty wax and hard wax. Partial decomposition of fatty lipids is obtained by—

(i) treatment of crude wax with high pressure steam and

(ii) initial fermentation of filter cake before it is dried and further processed.

The wax thus obtained is hard but also dark coloured and further treatment with nitric acid or potassium chromate with sulphuric acid with air blowing results in lightening the colour.\(^\text{12}\)

Cane wax recovery from filter mud was established in Ravalgaon on commercial scale and continued for over three decades. Similar wax extraction units were set up in Cuba and Australia. This industry however could not be established in the world in a big way.

4. MOLASSES

4.1. In the process of cane sugar manufacture the mother liquor obtained in the final stage of crystallisation, termed as final molasses is sent out from the process house and stored
separately, Cane sugar manufacture is accompanied by production of 3.5-4% molasses with approximate composition as follows—

(i) Water -> 15-20%
(ii) Sucrose -> 28-33%
(iii) Reducing sugar 10-15%
(iv) Total sugars 45-50%
(v) Ash 10-12%
(vi) pH 5.2-5.4.

With about 45-50% total sugars molasses constitutes an ideal and cheap raw material for sugar based fermentation industries. By fermentation of molasses different organic chemicals can be produced under influence of selective enzymes and specific micro organisms from the sugars present in molasses.

4.2. Alcohol manufacture—Ethyl alcohol or ethanol C₂H₅OH commonly known as alcohol is produced from molasses by fermentation under action of yeast Saccharomyces cerevisiae since decades in India and other sugar producing regions of the world. In batch system of fermentation molasses diluted to 15-20° Bx is transferred to large tanks and inoculated with yeast developed in molasses medium. Nitrogenous compounds are added and pH adjusted to 4.5-5 by dilute sulphuric acid. Fermentation is allowed to complete within 2-3 days, the proper temperature for fermentation being 32°-35°C. During fermentation which is anaerobic, CO₂ is evolved and ethanol formed at the expense of sugar. The fermented mash containing about 6-8% alcohol is pumped to distillation columns where ethanol is distilled off at 78°C and the hot stillage or slops separated from the bottom.

The distillation column is usually constructed of copper or stainless steel and alcohol produced in this is further purified in the rectifying column from which ethanol of about 96% purity is obtained. At somewhat higher temperature of 90° - 150°C in the distillation of wash, fusel oil containing different higher alcohols is separated. The ethyl alcohol yield is around 220-230 litres per tonne of molasses in the conventional batch process of fermentation.

In continuous fermentation introduced of late in the industry, diluted molasses is fed to a series of tanks interconnected at the top to allow continuous overflow of fermented mash from one tank into the next in series while fermentation reaction is completed in the last tank and the fermented beer is continuously withdrawn from it for being pumped into distillation unit.

4.3. Modern trends—In recent years in order to bring down the steam consumption from the level of 2.8-3 Kg/litre alcohol to 2.2 Kg./litre and improving the yields new systems and equipment designs have been developed. In new plants installed in India keeping in view the above factors the yield of alcohol has gone up from 220-230 litres/t molasses to 260-280 litres per tonne of molasses. Moreover in some new plants with continuous fermentation the alcohol percent in wash is 8-9% and fermentation efficiency attained is 90% as against 83-85% obtained in conventional batch fermentation plants. Technological
innovations aimed at achieving the above efficiencies are introduced in new designs of plants like Biostill, Vogel Busch, Encillium process distilleries.

4.4. Distillery by products—During fermentation of sugar C0₂ is evolved at the rate of 160 kg. per tonnes of molasses out of which 80-85% can be recovered. The C0₂ collected, passes through scrubber, is washed and under high pressure liquified or sold as dry ice. C0₂ is used in beverages in food preservation and other industries.

(b) Fusel oil—This is a mixture of 2-3 alcohols, major portion (70-80%) being amyl alcohol which is of commercial use as solvent for resins etc.

(c) Yeast—Yeast from stillage which is rich in protein can be used as cattle feed provided it is separated from alcohol wash, washed and dried.

(d) Spent wash—Disposal of distillery spent wash proves a headache if the same is discharged into fields or allowed to contaminate public stream on account of its deleterious effects on environment. The approximate composition of spent wash from Indian distilleries is as under—

(i) pH 4.5
(ii) B.O.D. 35000-45000 ppm.
(iii) Total solids 80000 -100000 ppm.

It is pertinent to note that all the ash constituents of molasses besides the unfermented organic matters are thrown out in the spent wash and its proper disposal envisages

(i) avoiding environmental degradation
(ii) recovery of important minerals like potassium for being used as fertiliser
(iii) Generation of energy from high organic matter contained in stillage.

The systems which have been developed towards this end are

(i) Generation of methane, CH₄ which can be burnt in boilers for supply of steam and power
(ii) concentration and composting
(iii) Incineration after concentration.

4.5. Chemicals from alcohol—Ethanol obtained from renewable agriculture based source has the potential to become the most important feed stock for a large number of chemical processes, on account of the rising price of petroleum products which are used presently in the manufacture of number of chemicals. Few of these alcohol based organic chemicals are being produced in Indian industry. Some of these important ethanol based chemicals are as under—

(i) Dehydration of ethanol at high temperature yields ethylene CH₂CH₂ which can be further processed to produce polyethylene, styrene, polyvinyl chloride etc.

(ii) Acetone is produced from ethanol by passing it over a catalyst at high temperature, which is useful in different industries as solvent and also for manufacture of other products.
(iii) Acetic acid is produced by oxidation of ethanol in the presence of catalyst.

Various derivatives of acetic acids are used in industry. Apart of its use as base for host of important chemicals alcohol is required also in different products of common use like cosmetics, coatings, varnishes etc.

4.5.1. Industrial alcohol is thus widely used in industry—

(i) for the manufacture of chemicals like acetic acid, acetaldehyde etc.

(ii) in pharmaceutical preparations

(iii) as solvent in chemical industry.

It can be further processed into potable liquors or denatured by blending with it small amount of pyridine like chemicals, for being used in heating or lighting.

4.5.2. Industrial alcohol contains 3.5 to 4% water and can be transformed into absolute alcohol or anhydrous alcohol by removing this water. The process usually adopted for dehydrating the industrial alcohol consists in mixing it with benzene or ethyl ether and subsequent distillation. During distillation the mixture of ethyl alcohol water with the third chemical agent possesses a boiling point lower man that of either ethyl alcohol and water. This constant boiling mixture or azotrope separates out water from the ethyl alcohol during distillations.

Apart from its use in the pharmaceutical industry and chemical laboratories, absolute alcohol serves as a good fuel in internal combustion engines in place of petrol. The alcohol has the added advantage of giving high octane rating and good thermal efficiency. Blending of petrol or gasolin with absolute alcohol has yielded good results with automotive engines. Brazil has in the past two decades achieved remarkable progress in their programme of producing absolute alcohol on a huge scale for use in the internal combustion engines.

4.6. Other products from molasses—

4.6.1. Apart from ethyl alcohol there are a number of chemicals of industrial importance which can be produced by fermentation process employing different micro-organisms. These are—

(i) Acetic acid

(ii) Butanol and acetone

(iii) Lactic acid

(iv) Glycerol.

4.6.2. Yeast

(i) Baker's yeast employed in leavening bread dough is produced from molasses using saccharomyces cerevisiae.

(ii) Food yeast or feed yeast is a single cell protein with high nutrition value and can be produced from molasses employing Torulopsis Utilis', a type of yeast. Yeast can serve as an important ingredient for fortification of cattle feed.
(iii) Production of monosodium glutamate MSG which is flavouring agent in food industry by fermentation of molasses has been successfully tried.

(iv) Lysine: Lysine is an essential amino acid which is used as additive to animal feed to enrich its nutritional value. Pilot plant trials of production of lysine from cane molasses employing special strain of glutamic acid bacteria C Glutamicum in Taiwan have shown promising results with yield of about 30% on total sugar in molasses.

4.6.3. Animal feed—molasses is being used as feed for live stock in U.S.A. in a big way. Special feeds can be prepared by enriching the molasses with urea and some bagasse pith. However the molasses from sulphitation process can be used only in limited amounts on account of the deleterious effects, the sulphites have on the digestive tracts of animals. Molasses from defecation process of clarification practised in raw sugar production however, can be mixed in larger proportions in cattle feeds prepared out of bagasse pith or cane tops, urea, oilcake etc.

5. From the foregoing discussion it will be evident that out of the by-products of cane sugar manufacture bagasse and molasses produced in sizeable quantities can be grainfully utilised in augmenting the energy generation in developing countries. Bagasse offers potential for being used as raw material for fibre based paper and board manufacture besides generating large amount of electrical power for other industries, Molasses can be mainly used for the production of ethyl alcohol which can serve as feed-stock for manufacture of various chemicals and can also be converted into good fuel for internal combustion engines as Brazil has done in a big way. Moreover the stillage from alcohol producing distilleries can provide good fertiliser besides generating fuel for running the distillery. Thus by converting the by-products into various articles and chemicals of industrial signification the cane-sugar factories can enhance the stability of the main industry besides supplementing the energy sources of the country.
REFERENCES

BY PRODUCTS OF CANE SUGAR MANUFACTURE

SUGARCANE 100

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(A) BAGASSE

Direct use as poultry litter
Production of Animal feed
As fuel in Boilers for process
Generation of surplus Electric power
Fibre based industries
Furfural paper & paperboard
Xyitol
α-Cellulose
Plastics

(C) FILTER CAKE

Fertiliser in Fields
Wax and Fats
(D) MOLASSES

Ethyl alcohol
Mono sodium glutamate
Butanol acetone
Lactic acid
Food & fodder yeast
Cattle feed

CO₂ Slops as fertiliser Fusel oils Acetic acid etc. Rectified spirit Anhydrous alcohol as fuel for automotive use Potable liquors

SUCROSE

Household use Fruit canning Food products Pharmaceutical manufacture Chemicals like sucrose octa acetate Fatty acid esters mannitol

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**Properties of Dry Saturated Steam (Metric Units)**

**Table I**

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TABLE II
MEAN SPECIFIC HEAT OF SUPERHEATED STEAM
(Knoblach and Jakob)

This table gives the mean specific heat \( c \) of steam between its temperature \( t \) and the final temperature of superheat \( T \) (metric units).

This mean specific heat permits of calculation of the total heat in the superheated steam, \( \Lambda \):

\[
\Lambda = \lambda + c (T - t)
\]

- \( c \) = mean specific heat of the steam, at constant pressure, between \( t^\circ \) and \( T^\circ \) C
- \( t \) = saturation temperature of the steam at the pressure \( p \), in \( ^\circ \) C
- \( T \) = final temperature of the superheated steam, in \( ^\circ \) C
- \( \lambda \) = total heat of the saturated steam at pressure \( p \), in kcal/kg
- \( \Lambda \) = total heat of the superheated steam at \( T^\circ \) and pressure \( p \), in kcal/kg
- \( p \) = absolute pressure of the steam, in kg/cm\(^2\)
- \( c_0 \) = specific heat of saturated steam at pressure \( p \)

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<td>0-264166 U.S. gal.</td>
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<tr>
<td>1 g</td>
<td>0.001 kg</td>
<td>0035274 oz. (avoirdupois)</td>
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<td>2-204622 lb.</td>
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<td>1 quintal = 100 kg</td>
<td>1-9684 cwt (English)</td>
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<td>1 quintal = 100 kg</td>
<td>2-204622 cwt (American)</td>
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<td>1 tonne = 1,000 kg</td>
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<td>1 tonne = 1,000 kg</td>
<td>0-9842 long ton</td>
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<tr>
<td>1 kg/cm²</td>
<td>101325 N/m²</td>
<td>14-2233 lb./sq.in. (p.s.i.)</td>
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<tr>
<td>1 kg/m²</td>
<td>1000 N/m²</td>
<td>0-204816 lb./sq.ft.</td>
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<td>1 t/dm²</td>
<td>10000 kg/m²</td>
<td>10-2408 short ton/sq.ft.</td>
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<tr>
<td>1 t/dm²</td>
<td>10000 kg/m²</td>
<td>9-1436 long ton/sq.ft</td>
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<tr>
<td>1 cm of mercury at 25 °C=</td>
<td>13-56 cm of water at 20 °C</td>
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<tr>
<td>1 kg / m²</td>
<td>0-204816 lb./sq.ft.</td>
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<tr>
<td>1 kg / m² /m</td>
<td>0-062428 lb./sq.ft./ft.</td>
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<tr>
<td>1 kg / m³</td>
<td>0-062428 lb. / cu.ft.</td>
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<tr>
<td>1 kg / dm³</td>
<td>62-428 lb. / cu.ft.</td>
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</tbody>
</table>
Heat

1 kcal 3-9683 B. Th.U.

Calorific value

1 kcal /kg 1-8 B. Th. U./lb.

Heat transmission

1 kcal /m² /h 0-368669 B. Th.U./sq.ft./h
1 kcal /m² /h/°C 0-204816 B.Th.U./sq.ft./h/° F

Heat conduction through a plate

1 kcal/m² /h/° C/m 0-672 B. Th. U./sq.ft./h/°F/ft.
1 kcal /m² /h/° C/m 8-0636 B. Th. U. /sq.ft. /h / °F /in.

Combustion chambers

1 kcal /m³ /h 0-11237 B. Th.U./cu.ft. /h

Temperature

C 5/9 (F —32)
1° C (difference in temperature) 1-8° F

Work and power

1 J 0-7375 ftlb.
1 kgm 7-233 ftlb.
1 kgm / sec 0-01315 h.p.
1 ch 0-98632 h.p.
1 kW 1-341 h.p.

Evaporation rate

1 kg / m² 0-204816 lb./sq.ft.
1 kg/m² (from 0° to 100° C) 0-2428 lb./sq.ft. (from and at 212° F)
1 kg/m² /°C 0-113786 lb./sq.ft./° F

Capacity, area and volume

1 m² /t 9-765 sq.ft./short ton
1 m² /t 10-9366 sq.ft./long ton
1 1/t 0-032036 cu.ft./short ton
1 1/t 0-03588 cu.ft. /long ton
1 m² /m³ 0-3048 sq.ft/cu.ft.
1 m² /hhl 3-048 sq.ft./cu.ft.

Moment of inertia

1 m² kg wt. 7-233 lb.wt.-sq.ft.
1 m² k g 23-73 lb.-sq.ft
# TABLE IV
## CONVERSION TABLES - BRITISH TO METRIC UNITS

### Length

<table>
<thead>
<tr>
<th>British Unit</th>
<th>Metric Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch</td>
<td>2.54 cm</td>
</tr>
<tr>
<td>1 foot</td>
<td>0.3048 m</td>
</tr>
<tr>
<td>1 yard = 3 ft.</td>
<td>0.9144 m</td>
</tr>
<tr>
<td>1 mile = 1,760 yards = 5,280 ft.</td>
<td>1,609.344 m</td>
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</tbody>
</table>

### Area

<table>
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<th>British Unit</th>
<th>Metric Unit</th>
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<tr>
<td>1 sq.in.</td>
<td>6451.6 cm²</td>
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<tr>
<td>1 sq.ft. = 144 sq.in.</td>
<td>0.092903 m²</td>
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<tr>
<td>1 sq. yard = 9 sq.ft.</td>
<td>0.8361 m²</td>
</tr>
<tr>
<td>1 acre = 4,840 sq.yards</td>
<td>0.4047 ha</td>
</tr>
<tr>
<td>1 sq. mile = 640 acres</td>
<td>2.59 km²</td>
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### Volume

<table>
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<th>British Unit</th>
<th>Metric Unit</th>
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<tr>
<td>1 cu.in.</td>
<td>16.387 cm³</td>
</tr>
<tr>
<td>1 cu.ft. = 1,728 cu.in.</td>
<td>28.317 dm³</td>
</tr>
<tr>
<td>1 Imc. ft.</td>
<td>0.028317 m³</td>
</tr>
<tr>
<td>1 Imp. gallon</td>
<td>4.546 L</td>
</tr>
<tr>
<td>1 U.S. gallon</td>
<td>3.785 L</td>
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</table>

### Weight

<table>
<thead>
<tr>
<th>British Unit</th>
<th>Metric Unit</th>
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<tbody>
<tr>
<td>1 oz. (avoirdupois)</td>
<td>28.35 g</td>
</tr>
<tr>
<td>1 lb. = 16 oz.</td>
<td>453.59 kg</td>
</tr>
<tr>
<td>1 cwt. (American) = 100 lb.</td>
<td>45.36 kg</td>
</tr>
<tr>
<td>1 cwt. (English) = 112 lb.</td>
<td>50.80 kg</td>
</tr>
<tr>
<td>1 short ton (American ton) = 2,000 lb.</td>
<td>907.185 kg</td>
</tr>
<tr>
<td>1 long ton (English ton) = 2,240 lb.</td>
<td>1,016.047 kg</td>
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</table>

### Pressure

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<tr>
<th>Pressure Unit</th>
<th>Metric Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lb./sq.in. (p.s.i.)</td>
<td>0.0703 kg/cm²</td>
</tr>
<tr>
<td>1 lb./sq.ft.</td>
<td>4882.4 kg/m²</td>
</tr>
<tr>
<td>1 short ton/sq.ft.</td>
<td>0.09765 t/dm²</td>
</tr>
<tr>
<td>1 long ton/sq.ft.</td>
<td>0.10937 t/dm²</td>
</tr>
<tr>
<td>1 in. mercury at 80° F</td>
<td>113 ft. water at 70° F</td>
</tr>
<tr>
<td>J</td>
<td>114 ft. water at 130° F</td>
</tr>
<tr>
<td>2-316 ft. water at 80° F</td>
<td></td>
</tr>
</tbody>
</table>

### Fibre loading

<table>
<thead>
<tr>
<th>British Unit</th>
<th>Metric Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lb./sq.ft.</td>
<td>4882.4 kg/m²</td>
</tr>
<tr>
<td>1 lb./sq.ft./ft.</td>
<td>16018.5 kg/m²/m</td>
</tr>
<tr>
<td>Property</td>
<td>Unit</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>1 Ib./cu.ft.</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>1 B. TH. U.</td>
</tr>
<tr>
<td><strong>Calorific value</strong></td>
<td>1 B. Th. U./lb.</td>
</tr>
<tr>
<td><strong>Heat transmission</strong></td>
<td>1 B. Th. U./sq.ft./h</td>
</tr>
<tr>
<td></td>
<td>1 B. Th. U./sq.ft./h°F</td>
</tr>
<tr>
<td><strong>Heat conduction</strong></td>
<td>1 B. Th. U./sq.ft./h°F/ft.</td>
</tr>
<tr>
<td></td>
<td>1 B. Th. U./sq.ft./h°F/in.</td>
</tr>
<tr>
<td><strong>Combustion chambers</strong></td>
<td>1 B. Th. U./cu.ft./h</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1, F (temperature difference)</td>
</tr>
<tr>
<td><strong>Work and power</strong></td>
<td>1 ft.lb.</td>
</tr>
<tr>
<td></td>
<td>1 h.p. = 550 ftlb./sec</td>
</tr>
<tr>
<td></td>
<td>lh.p.</td>
</tr>
<tr>
<td></td>
<td>1 h.p.</td>
</tr>
<tr>
<td><strong>Evaporation rate</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 lb./sq.ft. /h (from and at 212°F)</td>
</tr>
<tr>
<td><strong>Capacity, area and volume</strong></td>
<td>1 sq.ft. /short ton</td>
</tr>
<tr>
<td></td>
<td>1 sq.ft. /long ton</td>
</tr>
<tr>
<td></td>
<td>1 cu.ft. /short ton</td>
</tr>
<tr>
<td></td>
<td>1 cu.ft. /long ton</td>
</tr>
<tr>
<td></td>
<td>1 sq.ft. /cu.ft.</td>
</tr>
<tr>
<td></td>
<td>1 sq.ft. /cu.ft</td>
</tr>
<tr>
<td><strong>Moment of inertia</strong></td>
<td>1 lb.wt.-sq.ft</td>
</tr>
<tr>
<td></td>
<td>1 lb.-sq.ft</td>
</tr>
</tbody>
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