Design Based Improvement in a Three Pan Jaggery Making Plant For Rural India

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Abstract

Jaggery making is among the major agro processing industries found in rural India. Nearly 50% of total sugarcane produced in the country is used to manufacture about 8 million tonnes of jaggery, which is known to be the most nutritious agent among all sweeteners. Jaggery making plants are generally small units fabricated by local artisans and run by villagers in different parts of India. These plants are designed and fabricated on the basis of age old expertise without any technical support. Bagasse is used as fuel in these units to boil the sugarcane juice. Due to the crude and improper design, energy losses are high in these units resulting into higher fuel consumption. In order to reduce the losses and cut down the consumption of bagasse, an efficient three pan jaggery making plant is designed and studied. The improved plant and the conventional plant are compared on the basis of four parameters viz. jaggery production, bagasse consumption, emissions and temperature of exhaust. The Improved unit resulted in about 12% reductions in bagasse consumption, about 23% increases in jaggery production capacity, lesser emissions and comparatively lower exhaust gas temperature.

Keyword: Jaggery; three pan Jaggery making unit; Bagasse.

1. INTRODUCTION

Jaggery (also called as gur in India, Desi in Pakistan, Panela in maxico and South America) is a traditional sweetener which is produced in addition to sugar from sugarcane. It is produced by boiling off sugarcane juice in small jaggery making plant to solid jaggery, which contains 65-85% sucrose [1]. Compared to other sweeteners, jaggery contains iron (11%), calcium (0.4%), phosphorous (0.045%), glucose and fructose (10-15%), protein (0.25%) and fat (0.05%) [2]. Jaggery is prepared in small plants from sugarcane juice in rural areas. These plants basically consist of an underground furnace over which sugarcane juice is boiled off in large boiling pans. The sugarcane juice is produced by crushing of sugarcane in crushers and the bagasse is left over. After drying in sun, the left over bagasse is used as fuel in the furnace. The exhaust gases are released into the atmosphere through a vertical chimney. The sugarcane juice in the boiling pans is further clarified during the boiling stage it is mostly done by using lime (calcium hydroxide). Calcium acts as complexing agent and form scum, which is removed from time to time during boiling. Lime addition simultaneously increases the normal pH of juice from 5.2-5.4 to 6.0-6.4 [3].

It has been observed that furnaces and chimney of these plants are not properly designed, large proportion of produced heat is wasted and dense smoke is generally observed through the chimney of these conventional plants, as a result, bagasse consumption is very high in these plants. Jaggery making is a dominant cottage industry in India engaging over 2.5 million people. In case the bagasse is used optimally, a significant quantity of it can be saved, which may be further put to other useful applications such as paper and pulp industry, mushroom growing, as a direct charged fuel and for the production of ethanol, n-butanol etc, thus leading to additional income to the people involved in this activity [3-5]. Apart from its direct fuel use, bagasse gives rise to: pulps for rayon and absorbent products; particleboards and fibreboards; fuel briquettes, charcoal and producer gas; animal feeds (Bago-molasses); edible mushrooms (notably Pleurotus); chemicals (furfural, furfuryl alcohol, xylitol, Sucrolin, ethanol), activated carbon, and hydrolysed pith poultry feed. Cane molasses is mostly used for making ethanol (and hence chemicals derived by dehydration, oxidation or modification), many other fermentation products and various animal feeds; novel products include ephedrine hydrochloride, Ifop biocide and Nitromiel explosive. Sugarcane trash (tops, leaves) are used as fuel, mulch, and animal feeds. Filter press mud can be used as fertilizer, and is the usual source of cane wax; it can also be used in making biogas, animal feed and cement, and (mixed 1:12 with bagasse) in boilers, where it facilitates mechanical removal of ash. Bagasse ash is also used in making glass [6]. Besides this the saved bagasse may be used in other industries to be used as fuel and may provide Clean Development Mechanism (CDM) advantage. CDM provides an incentive to invest in emission reduction projects in developing countries to achieve reduction in $CO_2$ emissions at lowest cost that also promotes sustainable development in the host country. Bagasse cogeneration projects could be of interest under the CDM as they directly displace greenhouse gas emissions while contributing to sustainable rural development [7].
Process of jaggery making is almost same in every part of the Indian subcontinent but there is a difference in the design of plants being used for jaggery making. In the northern Indian states of Uttar Pradesh and Uttarakhand, three pan jaggery making plant is popular, however in the state of Maharashtra single pan and four pan plants are popular. It is evident that bagasse can be saved for other application only when the combustion & thermal efficiency of the jaggery plants are improved. Anwar [8] has suggested providing parallel fins at the bottom of boiling pans to enhance the heat transfer. Charging of bagasse too has an impact on the thermal efficiency of jaggery making plants [9]. Therefore, to improve the performance of jaggery making plants, more technical intervention is required to improve its combustion efficiency and thermal efficiency, making the process more efficient, profit making and environment friendly [10-12]. Also the technical knowhow involved in the manufacture of jaggery is very crude which can be improved through application of modern technology taking into consideration the ecological factors. Because of great importance of jaggery, proper care should be taken to improve the jaggery industry and sugarcane cultivation for jaggery making, which is presently in a neglected state [13-14]. An improved three pan jaggery making plant is therefore designed and studied in this paper.

2. EXPERIMENTAL

To conduct the experimental trials, two actual jaggery making plants were fabricated, one with conventional design and other with improved design of furnace, fire gratings and chimney with exhaust gas damper.

2.1 Conventional design

A conventional three pan jaggery making plant consists of one vertical three roller sugarcane crusher, three mild steel boiling pans of 457-559 mm thickness and 1524-1575 mm diameter. Ordinary masonry bricks, cement, sand and earth clay is used for its construction. The process of jaggery making in a three pan plant is a continuous process and requires 7-8 skilled manpower to work on. During the start of process all three boiling pans are filled with sugarcane juice and fuel (bagasse) is charged through a charging hole below the boiling pan-3. The maximum temperature is found below the boiling pan-3, which is around 1000 °C. Heat transfer under this boiling pan is mainly through convection and radiation. Rest other two boiling pans also fetch some heat through convection from the hot flue gases moving towards the chimney under a continuous draft. Cleaning of scum during the process is done on first two pans using calcium chloride, sodium hydrosulphide / wild lady finger stems etc. After the sugarcane juice in the boiling pan-3 is converted into solid jaggery by evaporation, the second batch of pre-heated sugar cane juice of boiling pan-2 is poured into boiling pan-3 and preheated sugar cane juice of boiling pan -1 is poured into pan-2 while fresh sugar cane juice comes into the boiling pan-1 through a pipe from the sugar cane crusher. In this way a continuous process of jaggery making is initiated with sugar cane juice finally getting evaporated into solid jaggery in boiling pan-3 and fresh juice getting preheated in the rest two boiling pans. From the data collected from local farmers, it is found that on an average 100 kg of sugarcane produces 10-12 kg of jaggery in north Indian areas and 600–800 kg of jaggery is produced in a single day with these conventional three pan jaggery making plants. Process flow chart of a typical three pan jaggery making process is shown in Fig.1.

2.2 Improved design

Improvement in the three pan jaggery making plant is stressed mainly towards the better design of furnace and chimney which would improve the combustion of fuel (bagasse) thereby increasing in heat addition to the process. The improved design of three pan jaggery making plant is shown in fig. 1. For the constructing of furnace in the improved plant, fire bricks (40-50% alumina) are used in place of ordinary masonry bricks. To achieve the intimate mixing of fuel and combustion air, a cast iron fire grate is provided in the furnace. The fuel (bagasse) charged into the furnace, falls on these grates and burns combining with air intake through furnace front wall openings as well as that entering through the bottom openings of fire grates. Also the ash gets automatically dropped through the grating and can be easily taken out periodically. Another major design improvement is the improved chimney. The improved chimney has circular cross section with an optimum height. The height of the chimney is calculated through experimental and practical methods. The improved chimney provides a smooth flow of exhaust gases with sufficient draft. Two sliding exhaust gas dampers made of M.S plate, are provided in the chimney to control the draft.
THEORY

Exact calculation of thermal efficiency based on theoretical relations is very difficult in case of three pan jaggery making plants, as some the parameters are not known and controlled efficiently e.g. optimum fuel charging rate, specific heat of sugarcane juice from boiling pan-1 to boiling pan-3 etc. However, some work has been done to find convective heat transfer coefficient of jaggery during boiling from sugarcane juice to solid jaggery [15]. A comparison of thermal efficiency and combustion efficiency can only be made based on the jaggery production, fuel consumption, temperature of exhaust gases and quality of exhaust gases. In context to this comparative performance trials were conducted on a conventional three pan jaggery making plant and improved plant to evaluate bagasse consumption and jaggery production quantitatively and chimney smoke qualitatively. Both the plants were run in similar conditions during a jaggery production shift (normally 16-18 hrs.). Observations were made at regular intervals for a batch of fixed volume of fresh sugar cane juice which was charged into the boiling pan-1. The weight of bagasse consumed in the furnace for the charged juice and quantity of Jaggery produced out of it were noted at regular intervals. Smoke number was measured using a Testo, smoke meter, CO2% with Horiba PG-250 gas analyzer and temperature of the flue gases were monitored with a K-type thermocouple.

RESULTS AND DISCUSSION

Experimental trials were conducted on both the conventional and improved three pan jaggery making plant, consumption of fuel (bagasse) and production of jaggery was observed. The consumption of bagasse per kg. of jaggery produced in conventional three pan jaggery making plant is 2.26 kg i.e. 2.26 kg. of fuel is used to produce one kg. of jaggery. Whereas, in improved three pan jaggery making plant 1.99 kg. of fuel is used to produce one kg. of jaggery, which is almost 12% reduction in fuel consumption. Per day production capacity has also increased from 762 kg. of jaggery to 937 kg. of jaggery, which is almost 23% increase in production capacity as shown in table 1 and 2. Increased percentage of CO2 in the exhaust gases signifies the better combustion of fuel in the plant furnace, as more CO2 implies less CO. The improved plant has comparatively high CO2% than conventional three pan jaggery making plant. A comparison of exhaust gas emissions, in terms of CO2 % for both the designs is shown fig. 3.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Time (hr:min)</th>
<th>Quantity of sugarcane juice (kg.)</th>
<th>Consumption of Bagasse (kg.)</th>
<th>Jaggery production (kg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>5:13</td>
<td>1500</td>
<td>418</td>
<td>178</td>
</tr>
<tr>
<td>Conventional</td>
<td>6:05</td>
<td>1500</td>
<td>648</td>
<td>288</td>
</tr>
<tr>
<td>Conventional</td>
<td>6:30</td>
<td>1500</td>
<td>657</td>
<td>296</td>
</tr>
<tr>
<td>Improved</td>
<td>6:26</td>
<td>1800</td>
<td>570</td>
<td>279</td>
</tr>
<tr>
<td>Improved</td>
<td>5:41</td>
<td>1800</td>
<td>673</td>
<td>316</td>
</tr>
<tr>
<td>Improved</td>
<td>6:13</td>
<td>1800</td>
<td>625</td>
<td>342</td>
</tr>
</tbody>
</table>
Fig. 2. CO2% in exhaust gas from chimney of improved and conventional jaggery making plant

Smoke no. signifies the concentration of unburnt carbon particles in the exhaust gas; high smoke no. refers to more unburnt carbon particles. Exhaust of the improved plant has shown lower smoke numbers as compared to conventionally designed plant. A comparison of the Smoke numbers is shown fig. 4.

Temperature profile of exhaust gases for both the improved and conventional designed plants is shown in fig 5. Temperature of the exhaust gases is directly related to the amount of heat being unutilized in the process and it is one of the major losses of the process. Temperature of the exhaust gases from improved furnace has lower temperature profile during the entire process as compared to the conventional design, which reflects that more heat is being used from the combustion of bagasse to the process of making jaggery. These results can be directly correlated to the increase in thermal efficiency and combustion efficiency of the improved three pan plant.

Fig. 3 Smoke No. of exhaust gases of improved and conventional jaggery making plant

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Conclusion

The experimental results shows that the three pan jaggery making plant, made with fire bricks, fire grates, improved chimney and dampers can significantly improve the performance of jaggery making such plants. Per shift sugarcane processing capacity has increased from 4500 lit. to 5400 lit. and by working for 30 min. extra in a shift, 23% extra jaggery can be prepared in the improved plant with 12% saving of fuel. The improved design has also resulted in better combustion of bagasse in the furnace as the CO₂% and Smoke no. is comparatively better than that of conventional design plant. Therefore, it can be concluded that the improved three pan jaggery making plant has improved thermal efficiency and impinges comparatively lesser pollution hazard to the atmosphere than the conventional plant. However, still there is a large scope of improvement in the performance of such plants by improving the combustion of fuel in the furnace, implementing better heat transfer systems and heat recuperation systems and by using filters and scrubbers in the system, emissions can be reduced to very low levels.

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