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Improving the performance of jaggery making unit using solar energy☆

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Summary The thermal performance of open earth pan furnace used conventionally for preparing jaggery (gur) is very low. Dry bagasse is used as a fuel to produce heat in a combustion process in the open earth furnace. The energy loss due to inefficient combustion process, the energy loss through exhaust gases and other losses due to furnace wall, convection and radiation bring the thermal efficiency of open earth pan furnace to a low value. Certain quantity of energy produced in combustion process is used to sensibly heat the sugarcane juice to its evaporation temperature. Solar collectors can supply the sensible heat required to raise the sugarcane juice temperature up to its boiling point, thereby reducing the total quantity of heat required in preparing the *jaggery*. Solar drier can be used to supply hot air required for the combustion process to burn the bagasse in more efficient manner. This paper presents analytical calculations done to study the performance improvement of the jaggery making unit using solar collector and solar drier.

Introduction

Jaggery prepared conventionally in open earth pan furnaces has been used as a sweetener in many places of India from ancient times. Sugarcane juice and bagasse extracted after crushing sugarcane are used as the raw materials to prepare jaggery. Out of total sugarcane annually produced in India, around 2/3rd is used to produce sugar, 1/5th used to produce jaggery and remaining is used for other commercial purposes (Anwar and Fuel, 2010). The preparation of jaggery is considered as a small scale industry, giving employment to many formers in rural India. Jaggery contains 65—85% of sucrose, 10—15% of reducing sugars, 3—10% of moisture, and the remaining is insoluble matter (Rao et al., 2007).

Mechanical and thermal energies are required to prepare jaggery using open earth pan furnace. Mechanical energy is required to crush the sugarcane to produce sugarcane juice,

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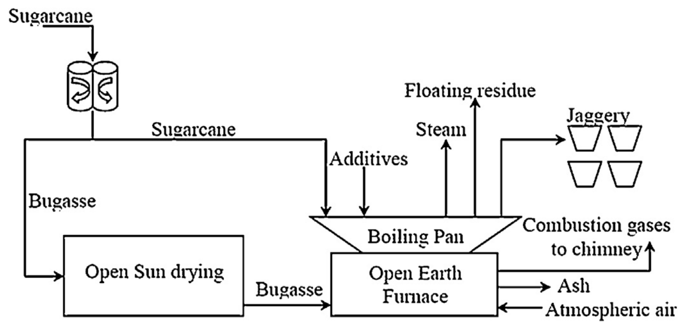

Figure 1 Conventional process of jaggery preparation.

and thermal energy is required to heat the sugarcane juice to prepare jaggery in the furnace. Crushing the sugarcane will produce sugarcane juice and bagasse as a by-product. At the initial moment the moisture content in the bagasse is around 40—50% (Manohar Rao, 1977). The moisture content can be reduced to 8—10% by drying the bagasse in open area, and then dry bagasse is used as a raw material to produce heat by combustion in the open earth furnace. It was observed that out of the total energy produced in the combustion process, around 45% is used for jaggery preparation and remaining is lost through flue gases, ash and furnace walls. Sugarcane juice used in preparation of jaggery in the open earth pan consists of three different stages. The first stage of process begins with supplying sensible heat (around 6% of total energy produced in the combustion process) required to raise the temperature of sugarcane juice from ambient to its boiling point. Measured quantity of additives like bendi, calcium carbonate and phosphoric acid (each at around 30—50 g/100 kg of sugarcane) will be added to the sugarcane juice to maintain the required pH in this stage (Ghosh et al., 1998). The second stage consists of removal of water from the sugarcane juice at its saturation/boiling temperature. The amount of heat supplied during this stage (around 39% of the total energy produced in the combustion process) is considered to be latent of vaporization required to convert water to steam. Floating residue known as molasses (around 3—5 kg/390 kg of sugarcane juice) is formed at this point and needs to be removed from the free surface. At the end of the second stage, the sugarcane juice will become rich in concentrated solids as the water is completely removed. In the last stage of jaggery preparation, the heat supplied (around 0.1% of the total energy produced) is utilized to increase the temperature of the sugarcane juice from its boiling point to striking point. The striking point is the temperature at which the sugarcane juice converts to a semisolid paste which slides on the pan surface instead of sticking to the pan. At this stage the sugarcane juice in semi-solid state is removed from the pan and cooled to room temperature to prepare the jaggery. The conventional process of jaggery preparation is represented in Fig. 1.

This paper discusses the use of solar energy in the supply of partial or full amount of the heat required in the first and second stages of jaggery preparation. Combustion efficiency of the open earth furnace can be increased by using preheated air in place of atmospheric air and bagasse with low moisture content at the inlet to the furnace. Solar collectors and solar driers can be used as a source of heat in the jaggery preparation. Sugarcane juice can be heated to its boiling temperature using solar collectors and then send to the boiling pan for jaggery preparation. Solar drier can be used to preheat the air supplied to the furnace and remove the moisture content from the bagasse which enhances the combustion efficiency. The suggested modified process of jaggery preparation with solar energy as a heat source is shown in Fig. 2.

Mathematical modelling

Applying conservation of mass, Eq. (1) is used to write mass balance between various inputs and outputs to the Jaggery preparation unit.

$$(\dot{m}_{in} - \dot{m}_{out}) + \dot{m}_{gen} = \frac{\partial m}{\partial t} \tag{1}$$

For a steady state operation and assuming there is no mass generation Eq. (1) can be modified as,

$$(\dot{m}_{in} - \dot{m}_{out}) = 0 \tag{2}$$

In Eq. (2), $\dot{m}_{in}$ and $\dot{m}_{out}$ are the total mass flow rate in and out to the production unit. The various mass quantities supplied to the production unit are mass of sugarcane juice, additives, dry bagasse and combustion air. The various mass quantities produced from the production unit are mass of jaggery, floating residue, steam, flue gas and ash. Along the combustion line and sugar cane to jaggery preparation line the mass conservation results in,

$$\dot{m}_{db} + \dot{m}_{da} = \dot{m}_{fg} + \dot{m}_{ash} \tag{3}$$

$$\dot{m}_{sj} + \dot{m}_{add} = \dot{m}_{jag} + \dot{m}_{fr} + \dot{m}_{st} \tag{4}$$

In Eq. (3), $\dot{m}_{db}$, $\dot{m}_{da}$ are the mass flow rates of dry bagasse and dry air supplied for combustion. $\dot{m}_{fg}$ and $\dot{m}_{ash}$ are the mass flow rates of flue gases and ash produced in the combustion. In Eq. (4), $\dot{m}_{sj}$, $\dot{m}_{add}$ are the mass flow rates of sugarcane juice and additives, $\dot{m}_{sj}$ mass flow rate of jaggery produced, $\dot{m}_{fr}$ mass flow rate of floating residue and $\dot{m}_{st}$ is the mass flow rate of steam produced due to evaporation of water in the sugarcane juice.

Applying conservation of energy, Eq. (5) is used to write energy balance between various inputs and outputs to the jaggery preparation unit.

$$(\dot{E}_{in} - \dot{E}_{out}) + \dot{E}_{gen} = \frac{\partial E}{\partial t} \tag{5}$$