www.ThePharmaJournal.com

The Pharma Innovation

Heat and mass balance of IISR three pan jaggery furnace: A review

Suraj Kumar, Dilip Kumar, Shailesh Kumar Markam and Akash Patel

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(12): 331-335

www.thepharmajournal.com
Received: 01-09-2022
Accepted: 05-10-2022

Suraj Kumar
Research Scholar, Department of Agricultural Processing and Food Engineering, SV CAET & RS, FAE, IGKV, Raipur, Chhattisgarh, India

Dilip Kumar
Principal Scientist, Jaggery Unit, Division of Agricultural Engineering, ICAR-Indian Institute of Sugarcane Research (IISR), Lucknow, Uttar Pradesh, India

Shailesh Kumar Markam
Research Scholar, Department of Agricultural Processing and Food Engineering, SV CAET & RS, FAE, IGKV, Chhattisgarh, India

Akash Patel
Research Scholar, Department of Agricultural Processing and Food Engineering, SV CAET & RS, FAE, IGKV, Chhattisgarh, India

Corresponding Author:
Suraj Kumar
Research Scholar, Department of Agricultural Processing and Food Engineering, SV CAET & RS, FAE, IGKV, Chhattisgarh, India

Abstract

The production of jaggery (Generally known as “Gur”) is one of the most traditional processes generally produces in cottage industries. In the last few years there has been an increase in the exports of jaggery and higher volumes of production are required driving this activity from a rural process with small production to an industry seeking greater productivity. In this framework, optimization of the use of energy becomes essential for the proper development of the process of production and the correct performance of the involved equipment. In Indian Institute of sugarcane research (IISR), Lucknow has been developed a new three pan furnace for jaggery making. The heat exchangers containing sugarcane juice are placed over a flue gas duct. The thermal energy contained in the gas is used to evaporate the water contained in the sugarcane juice thickening the juice and after evaporating almost all the water, a pasty crystalline yellow substance is left in the boiling pan which becomes solid after cooling, this is the jaggery. The modelling and simulation of heat transfer between the combustion gases and the juice is very important in order to improve the thermal efficiency of the process. It permits to know with a high level of detail the physical phenomena of heat transfer occurring from bagasse combustion flue gases to sugarcane juice. This paper presents the results of the numerical simulation of heat transfer phenomena in the open heat exchangers and those results are compared to experimental research work data.

Keywords: Jaggery, furnace, heat, bagasse, fuel, pan

Introduction

Jaggery making is the oldest cottage industry in India. In financial year 2021, the yield of sugarcane produced across India was estimated to be approximately 82 metric tons per hectare (Statista, 2022) [1]. In India, almost 80% of the sugarcane produced is processed into white sugar, around 12% into jaggery and khandsari, and approximately 8% is used as seed cane. Per capita consumption of jaggery and sugar is 8.1 kg and 14.2 kg respectively. It indicates that about 36% sweetener need is provided by jaggery. Conventionally jaggery is produced by evaporation of water in open pans. Furnace is fired using bagasse, which is residue of sugarcane, obtained during juice extraction. Furnace heat utilization efficiency is very low, which is ~20% for single, ~30% for two, and 35 to 40% for four pans. It also depends on number of parameters like sizes of pan, furnace and chimney, flue gas flow patterns, orientation and air inlets, bagasse firing practices, etc.

The increase in the jaggery production can be achieved through the construction of new high capacity jaggery processing installations or by the modernization of the existing ones. Another fundamental aspect of the jaggery production process is fuel self-sufficiency, which means the amount of bagasse consumed during the jaggery production is less than the amount of wet bagasse produced during milling. Thus, jaggery installations are self-sufficient when there is no need to purchase more bagasse either to use other alternative fuels in the jaggery production. Significantly, fuel self-sufficiency helps to reduce the region deforestation and the greenhouse gases emissions. Jaggery production modules consist of following operational units where:

1. The sugar cane passes through a milling process in order to extract their juice,
2. By heating and evaporation, this sugar cane juice goes through a water extraction process with the purpose to obtain the syrup, the thermal energy necessary is produced in a furnace,
3. This syrup is crystallized by wooden agitation within a range of controlled temperature in order to get the jaggery as a final product.

Related Work

K. Sada Siva Rao *et al.*, (2003) [2] studied about the efficiency of traditional jaggery making furnace. In this paper thermal efficiency of single pan jaggery furnace was evaluated and reported to be 14.75%.

Singh R.D. *et al.*, (2009) [3] studied about the performance evaluation of two pan furnace for jaggery making. In this paper performance evaluation of two pan furnace for jaggery making developed by IISR, Lucknow was carried out. It is reported that efficiency of the two pan furnace is 29.3% as against efficiency of single pan furnace varying from 16% to 19.7%.

Sardeshpande V.R. *et al.*, (2010) [4] studied about the thermal performance evaluation of a four pan jaggery processing furnace for improvement in energy utilization. Jaggery furnace is proposed to establish furnace performance and loss stream analysis. The proposed method is used to investigate a four pan traditional jaggery furnace in India. The loss stream analysis indicates that the theoretical energy required for jaggery processing is only 29% of total energy supplied by bagasse combustion. The major loss is associated with heat carried in flue gas and wall losses. The air available for combustion depends upon the draft created by chimney in natural draft furnaces. The oxygen content in the flue gas is a measure of degree of combustion. A controlled fuel feeding based on the oxygen percentage in the flue gases is proposed and demonstrated. The traditional practice of fuel feeding rate is changed to control feeding rate leading to reduction in specific fuel consumption from 2.39 kg bagasse/kg jaggery to 1.73 kg bagasse/kg jaggery. This procedure can be used for evaluation of jaggery furnaces for identification and quantification of losses, which will help in improving thermal energy utilization.

S.I. Anwar, (2010) [5] studied about fuel and energy saving in open pan furnace used in jaggery making through modified juice boiling/concentrating pans. In this paper the concept of fins has been used for heating purpose for improving efficiency of open pan jaggery making furnace. Pan is the integral part of these furnaces where boiling/concentration of sugarcane juice take place. Parallel fins were provided to the bottom of main pan and gutter pan of IISR Lucknow 2-pan furnace. Choice for type of fins was based on movement of flames and hot flue gases generated due to combustion of bagasse. Fins helped in more heat transfer to the sugarcane juice being concentrated. Considerable improvement in heat utilization efficiency (9.44%) was observed which resulted in saving of fuel and energy (31.34%).The heat utilization efficiency of jaggery making furnace increased considerably by using modified pans having fins. Modification resulted in saving of fuel and energy. The saved bagasse can be diverted to paper and pulp industry for extra revenue generation. Improvement in efficiency would also be helpful for quality enhancement of the product due to less time requirement for sugarcane juice concentration in jaggery making.

Kiran Y. *et al.*, (2014) [6] studied about the energy improvements in jaggery making process. In this paper jaggery (unrefined sugar) is produced by evaporating water from sugarcane juice in steel pans situated over pit furnaces. While it delivers a health friendly sweetening agent with medicinal value (Singh *et al.*, 2009; Sahu and Paul, 1998) [3, 8] its performance, both in terms of technical efficacy and financial sustenance, is being questioned. In India, jaggery is produced in batch operations, of about 1 ton per day capacity. Bagasse is used as fuel for the process. Improving the efficiency of bagasse utilization is of interest because surplus bagasse could be used elsewhere as a fuel. If all energy in the bagasse were used to heat and evaporate water from the juice, calculations show the rate of bagasse consumption would be 0.65 kg bagasse per kg jaggery. Heat losses in flue gas at 1000 K with no excess oxygen are calculated to decrease the efficiency to 72% (0.90 kg bagasse per kg jaggery). In this study, two single-pan jaggery units were tested where in, efficiencies varied from53-76% and 50–57%. The higher efficiencies in each unit were obtained by blocking some of the air inlet holes to decrease the excess air flow. The second unit has a taller chimney than the first, which may contribute to greater air flow due to increased draft. Excess air contributes to lower combustion temperatures, causing a decreased rate of heat transfer to the juice. Minimizing excess air flow into the furnace is a possible strategy for increasing the efficiency of bagasse utilization and might be implemented quite easily by placing dampers at air inlets. This study also included tests of one four-pan jaggery unit. Measured efficiencies were about 50%. Radiative heat transfer to three of the four pans is calculated to be hindered substantially by a low view factor.

Performance evaluation of IISR three pan furnace

Jaggery processing is a small-scale industry in many states of India. Jaggery is being used as a sweetener since ancient days. Sugarcane-based jaggery production is one of the oldest processing industries. Sugarcane cultivation is carried out in around 4 million hectares of land in India and its production has been between 230 and 300 million tones in past several years. Jaggery (locally termed as *Gur* in India) and raw sugar (*Khandsari* in India) production from sugarcane juice are among the major agro processing industries. Present scenario of sugarcane-based industry indicates that about 70% of cane is utilized for sugar making, 20% for jaggery and *khandsari* and remaining is for sowing, feed and juice extraction for direct consumption.

Technically jaggery is a condensed form of a sugarcane juice, generally present in the solid state at ambient temperature. Jaggery is a traditional unrefined non-centrifugal sugar consumed in Asia, Africa, Latin America, and the Caribbean. It is a concentrated product of cane juice and can vary from golden brown to dark brown in color. It contains 65-85% sucrose, 10-15% reducing sugars, 3-10% moisture and the remaining (in traces) made up of other insoluble matter such as fat, proteins, minerals, iron and phosphorus. Hence, jaggery possesses nutritive properties of high order and is often called as medicinal sugar. Jaggery production mainly involves juice extraction, evaporation of water from the juice, stirring of condensed juice, granular formation and molding to solid state.

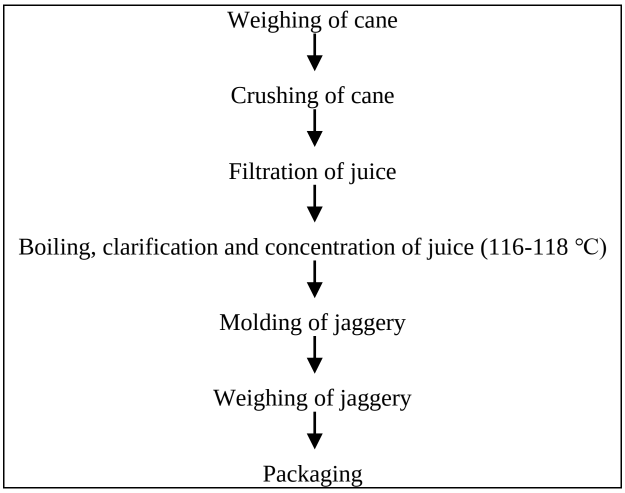

Fig 1: Process flow chart of jaggery production

A jaggery processing plant mainly requires mechanical and thermal energy for processing. Mechanical energy is mainly used for cane crushing, for which bullock driven crushers were used in olden days. Since last fifty years, electric motor and direct drive diesel engine are used as the mechanical drive for crusher.

In jaggery processing, juice is condensed in open pan by evaporation of water. Thermal energy for evaporation is provided by combustion of bagasse, which is a biomass generated during sugarcane crushing. Generally, all the bagasse generated during crushing is consumed (after drying) for evaporation of juice. In case of insufficient bagasse for thermal energy, other biomass like cotton stalk and soybean stalk is used. This calls for collection and transportation of biomass leading to inconvenience and increased cost of jaggery production. Shortage or no saving of fuel is very common with these furnaces due to low heat utilization efficiency.

Bagasse can be an input to many industrial processes as well as heat source (due to high calorific value and low ash content) and thus has market value. So any saving of bagasse can be a source of additional income to jaggery manufacturers. Thus it is important to operate the jaggery furnace efficiently to achieve the jaggery processing in the minimum quantity of bagasse for economic benefits. The traditional furnace included ordinary masonry bricks cemented with earth clay and a vertical chimney of rectangular cross-section, without any brickwork at the bottom or fire grate. Improved furnace was designed with use of firebrick with refractory cement and a chimney of circular cross section of optimum height to create sufficient draft. Improved chimney also included sliding dampers for draft control, firing platform for easy feeding of bagasse, fire grate for mixing of air with fuel. The specific bagasse consumption in traditional furnace was about 2.24 kg/kg jaggery which was improved to 1.96 kg/kg jaggery.

The second pan (termed as gutter pan) in the improved furnace is installed in the flue gas path of the first pan (termed as boiling pan). Other improvements were air preheating and installation of stepped grate. The conducted performance trials with evaporation of water in a two-pan furnace with and without external fins on flue gas heating side. His study reports increase in the furnace efficiency from 20% to about 29% with the inclusion of fins.

All these studies have reported experiments for the gross furnace performance and there are no loss stream quantifications for furnace. There are no methods reported & suggested for operational practices for improvement in heat utilization of existing furnace. It is observed that bagasse available after juice extraction falls short of the demand for the furnace operation, in majority of jaggery furnaces. An energy performance study is conducted for IISR three pan jaggery furnace located in Indian Institute of Sugarcane Research (IISR), Lucknow (U.P.). This paper reports the performance study with details about energy utilization in the furnace. This jaggery furnace performance evaluation includes the mass and energy balance with loss stream analysis. This is used to identify and evaluate the losses that can be avoided. Some methods for improving design and operation are also discussed.

Jaggery plants are generally constructed mainly consists of an underground furnace, like an open pan cooking stove, (bigger version of a biomass- based cooking stove) with a pan mounted on to it for evaporating the juice. The sketch diagram for jaggery plant is presented in Figure No.2. There are two types of jaggery furnace, single pan furnace and multiple pan (three to four pans) furnace. In a single pan furnace all jaggery making processes like sensible heating, chemical addition, impurity removal, evaporation etc. are carried out in single pan as a batch process while in a multiple pan furnace above jaggery making processes are carried out in three to four pans in a semi continuous mode.

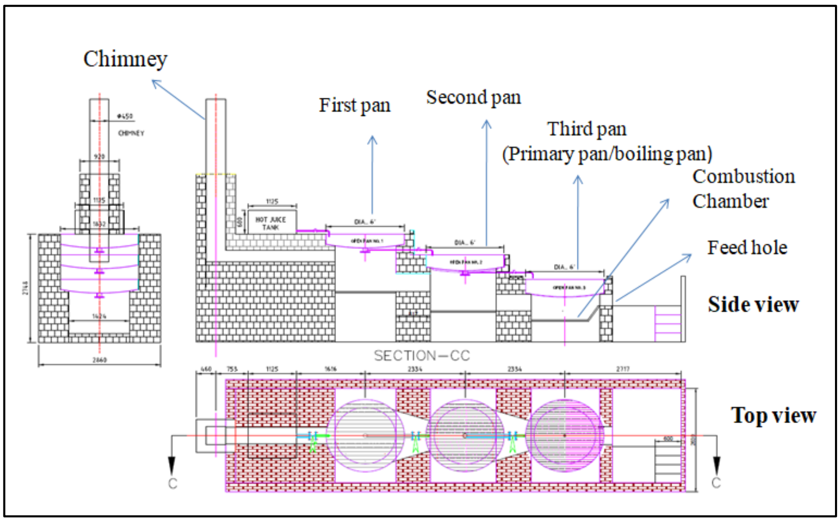

Fig 2: IISR Three Pan Jaggery Plant

Mass balance (also called as material balance) is an application of conservation of mass to the analysis of physical systems. By accounting for material entering and leaving a system, mass flows can be identified which might have been unknown, or difficult to measure without this technique. Mass balance for a jaggery furnace can be presented as in equation.
(Mass of juice + Mass of bagasse + Mass of combustion air + Mass of Okra Juice) = (Mass of flue gas + Mass of water evaporated + Mass of jaggery + Mass of ash + Mass of floating residue).
The above equation gives the gross mass balance for the control volume which can be divided into two non-interacting streams, namely juice processing and fuel combustion streams. The mass balance for sugarcane juice processed is presented by equation which can be used to estimate the moisture evaporated from the juice.

$M_{juice}+m_{okra} = m_{jag}+m_{evp}+m_{fr}$
$600+13 = 95+418+100$

Where mjuice = mass of juice per batch (kg); mjag = mass of jaggery produced per batch (kg); mevap = mass of moisture evaporated per batch (kg); mfr = mass of floating residue per batch (kg); mokra = mass of Okra juice per batch (kg); mchem = mass of chemicals per batch (kg).
The mass balance of the combustion of bagasse is presented in equation.

$\text{mbagasse} + \text{mair} = \text{mflue} + \text{mash}$

Where mbagasse = mass of bagasse per batch (kg); mair = mass of air for combustion per batch (kg); mflue = mass of flue gas produced per batch (kg); mash = mass of ash produced per batch (kg).
The mass of flue gas is estimated based on stoichiometric calculations, taking into account species balance for combustion products.
Energy balances are used to quantify the energy used or produced by a system. Energy balances are used in the examination of the various stages of a process, over the whole process. The energy balance for the control volume is presented in equation.
Rate of energy from bagasse = (Rate of energy for juice heating + Rate of energy for juice evaporation + Rate of energy carried in liquid jaggery + Rate of energy carried in flue gas + Rate of energy in wall loss + Rate of heat loss in ash + Rate of heat loss in un-burnt fuel)
The theoretical minimum energy required for the jaggery processing is presented in equation

$\text{Qjag} = \text{mjuice} \times \text{Cjuice} \times (\text{Tevap} - \text{Tamb}) + \text{mevap} \times \text{hfg} + \text{mjag} \times \text{Cjag} \times (\text{Tstri} - \text{Tevap})$
$\text{Qjag} = 600 \times 4.184 \times (118 - 22) + 418 \text{ x } 2270 + 95 \times 2 \times (118-100)$
$\text{Qjag} == 240.998 + 948.860 + 3.420$
$Q_{jag} = 1193.27 \text{ MJ}$
$Q_{jag} = 1{,}193{,}270 \text{ kJ}$

Where Qjag = minimum quantity of energy required for jaggery processed per batch (kJ); mjuice = mass of juice per batch (kg); Cjuice = specific heat of juice per batch (kJ/kg K); Tevap = temperature of evaporation of moisture (°C); Tamb = ambient temperature (°C); mevap = mass of moisture evaporated per batch (kg); hfg = latent heat of evaporation (kJ/kg); mjag = mass of jaggery produced per batch (kg); Cjag = specific heat of jaggery per batch (kJ/kg K); Tstri = striking temperature of jaggery (°C).
Energy supplied for jaggery process is by combustion of bagasse and can be expressed as

$\text{Qbagasse} = \text{mbagasse} \times \text{CVbagasse}$
$\text{Qbagasse} = 230 \text{ x } 18000$
$\text{Qbagasse} = 4140.00 \text{ MJ}$
$Q_{bagasse} = 41{,}40{,}000 \text{ kJ}$
Where Qbagasse = quantity of heat supplied per batch (kJ); mbagasse = mass of bagasse used as fuel in a batch (kg); CVbagasse = calorific value of bagasse (kJ/kg).

The energy loss associated with jaggery processing is presented in equations

$\text{Qloss} = \text{Qbagasse} - \text{Qjag}$
$\text{Qloss} = 41{,}40{,}000 - 1{,}193{,}270$
$\text{Qloss} = 2946730 \text{ kJ}$
Where Qloss = quantity of heat lost per batch (kJ).
$\text{Qloss} = \text{Qflue} + \text{Qwall} + \text{Qash} + \text{Qunburnt}$
Qwall = quantity of wall losses per batch (kJ); Qash = quantity of heat lost in ash per batch (kJ); Qunburnt = quantity of heat lost in un-burnt fuel due to incomplete combustion per batch (kJ), Qflue = quantity of heat lost through flue gases per batch (kJ.

There are losses associated with jaggery processing in the pan namely the convective & radiative heat loss from the pans surface (uncovered by juice), heat loss due to transfer of hot juice from one pan to other and heat loss during stirring of the juice (due to dipping of cold stirrer). These losses are negligible and difficult to quantify hence these are considered as a part of wall losses.
The energy loss from the flue gas and ash can be estimated using following equations

$\text{Qflue} = \text{mflue} \times \text{Cflue} \times (\text{Tflue} - \text{Tamb})$
Where Qflue = quantity of heat lost through flue gases per batch (kJ); mflue
=mass of flue gases per batch (kJ); Cflue = specific heat of flue gases (kJ/kg K); Tflue = temperature of flue gases (°C); Tamb = ambient temperature (°C).
$\text{Qash} = \text{mash} \times \text{Cash} \times (\text{Tash} - \text{Tamb})$
where Q ash = quantity of heat lost through ash per batch (kJ); m ash = mass of ash per batch (kJ); C ash = specific heat of ash (kJ/kg K); T ash = temperature of ash (°C); Tamb = ambient temperature (°C).

$$\text{Thermal efficiency} = \frac{\text{Heat output}}{\text{Heat input}}$$

$$\text{Thermal efficiency} = \frac{1193270}{4140000} \times 100$$

Thermal efficiency = 28.82%

Conclusion

In the above experimental work's results, we have considered average value of three sets of readings taken from plant. From above information estimated thermal efficiency of the plant is 28.82%. Performance improvement areas for the three pan jaggery plant can be concluded considering thermal efficiency in this work. Through the above results, we can conclude that some of the areas are there which can be further improved – like bottom surface of pan, interlining of furnace. heat loss due to flow of gases is much more as compare to other surface loss that can be minimum by using more or better insulating material, so as to trap this heat in it to allow more evaporation of water.

References

1. Annual yield of sugarcane in India FY 2014-2021, Statista Research Department, 2022; Mar 16.
2. Sada Siva Rao K. *et al.*, Effeciency of Traditional Jaggery Making Furnace, Madras Agricultural Journal. 9091-30 2003 Jan-March;184-185,
3. Singh RD. *et al*., Performance Evaluation of Two Pan Furnace For Jaggery Making, IE(I) Journal-AG, 2009 June;90:27-30,
4. Vishal Sardeshpande R, Shendage DJ, Indu Pillai R. Thermal Performance Evaluation of A Four Pan Jaggery Processing Furnace For Improvement In Energy Utilization, Energy. 2010;35:4740-4747,
5. S.I. Anwar, Fuel And Energy Saving In Open Pan Furnace Used In Jaggery Making Through Modified Juice Boiling/Concentrating Pans, Energy Conversion and Management. 2010;51:360-364,
6. Kiran Shiralkar Y, Sravan Kancharla K. *et al.*, Energy Improvements In Jaggery Making Process, Energy for Sustainable Development. 2014;18:36-48,
7. Jakkamputi LP. Mohan, Kumar J, Mandapati. Improving the performance of jaggery making unit using solar energy, Recent Trends in Engineering and Material Sciences. 2016; September;8:146-150.
8. Sahu AP, Paul BN. The role of dietary whole sugar-jaggery in prevention of respiratory toxicity of air toxics and in lung cancer. Toxicology Letters. 1998;95(1001):154.