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Performance Evaluation of a Modern Jaggery Plant with Bagasse Drying using Waste Heat Recovery from Surrounding Walls of Combustion Chamber

A. B. Shinde, S. N. Sapali, Y. V. Sonone
(Mechanical Engineering Department, College of Engineering Pune,India)

Abstract: *Jaggery processing is one of the traditional agro-based industries mainly found in rural parts of India. Most of jaggery processing units employ open earth pan furnaces for juice concentration with sugarcane bagasse as a primary fuel. In conventional jaggery plants, wet bagasse is spread over the ground and dried under sunlight. This bagasse drying technique is time-consuming, space consuming and labour intensive. In the rainy season, conventional bagasse drying is impracticable due to unavailability of intense sunlight. Also use of alternative fuels such as wood, automotive tyres, petroleum products etc. for the operation of jaggery plant is uneconomical and non-eco-friendly. The paper deals with the design and development of modern jaggery plant with bagasse drying mechanism using waste heat recovered from walls of the combustion furnace. The paper presents an experimental performance evaluation of jaggery plant and results validated with CFD simulation. The experimental results show that heat utilized for jaggery preparation is 24%, heat loss during the jaggery preparation is 72 % and the amount of heat recovered by wet bagasse from the furnace walls is 4 %. It is observed that 54.54 % of moisture is removed from the wet bagasse using waste heat recovery from surrounding walls of the combustion chamber.*

Keywords : *agro-based industries, CFD simulation, moisture removed, non-eco-friendly, waste heat recovered.*

I. Introduction

At present, 115 countries of the world cultivate sugarcane for sugar production and produce about 133 million tonnes of sugar and 10 million tonnes of jaggery. The conventional jaggery plants consist of a combustion chamber, which is underground and the pan containing sugar juice is placed over the combustion chamber on the earth surface. Dry bagasse is used as a fuel during jaggery production. For drying the wet bagasse it requires large space and time as well as it depends on the availability of solar radiation. Moisture present in the bagasse reduces its calorific value. During the combustion process of dry bagasse large amount of heat is lost to the surrounding area. Many researchers have attempted various methods and technology to remove moisture content from wet bagasse to improve the gross calorific value. M. Esther Magdalene Sharon et al. have done the research work on energy losses in traditional jaggery plant. The efficiency of the crushing and concentration process is 60% and 14.75% respectively. He concluded that by using steam jacketed vessels for concentration, circulation of cooled water for cooling the hot jaggery and recirculating it for steam production and during crushing will make the jaggery processing energy efficient[1]. J. Sudhakar et al. have developed the bagasse dryer to reduce the moisture content from wet bagasse. The average moisture content in the bagasse is 51.5%. they observed that after installation of bagasse dryer about 45% of wet bagasse was routed through the dryer[2]. Mr R. J. Panchal et al. have developed the charts for calorific values and bagasse composition [3]. Several researchers work on the jaggery processing industry to improve the performance and to recover the heat from exhaust gases. The heat content in the exhaust gas can be utilised for drying of bagasse and preheating of sugarcane juice in the preheater. Appasaheb manjiare et al. have shown that the thermal efficiency can be improved from 16% to 24 % and bagasse consumption is reduced by 1.2 Kg per Kg jaggery production by utilizing heat from exhaust gas for preheating the sugarcane juice in preheater [4]. Lakshmi pathi jakkamputi et al. worked on the performance improvement of jaggery plant using solar energy. The sensible heat required for jaggery preparation is utilised from solar panels [5]. S. I. Anwar has worked on the determination of moisture content from bagasse using a microwave oven. It took about 20 to 25 minutes for the determination as compared to 8-10 hours in a conventional hot air drying method [6].

Many researchers worked on performance improvement of traditional jaggery plant with various kinds of heat recovery and combustion technology, but no one has worked on heat recovery system from walls of the combustion chamber which can be utilised for drying the wet bagasse. The paper presents the methodology to utilise the heat from the combustion chamber for drying the bagasse. The currently developed portable jaggery plant is very simple and cost-effective as shown in Fig.1.

Fig.1 Modified portable jaggery plant

The experimental set up consists of a portable jaggery plant with a feeder system in front side for continues supply of bagasse to the combustion chamber. Made up of a steel plate having a thickness of 3 mm. At top of the combustion chamber, the juice pan is placed where heat is supplied from bottom to boil sugarcane juice. A cage is fabricated surrounding walls of the combustion chamber for holding the wet bagasse. During experimentation, the bagasse packed in a cage surrounding the combustion chamber gets dried due to radiation and convection of hot air flowing from inside to outside.

II. Numerical Analysis

The temperature of the steel plate is an essential variable of the project as the quality of bagasse drying depends on the plate temperature. Bagasse near the plate surface may stick to the plate due to the high temperature of the plate than the self-ignition temperature of bagasse. The partial arrangement of the combustion chamber and the bagasse packed surrounding it is shown in Fig.2. There is a gap of 50mm between the steel plate and bagasse. The dry bagasse is burnt in the combustion chamber so as to get the heat flux at a rate of 4800 W/m^2.

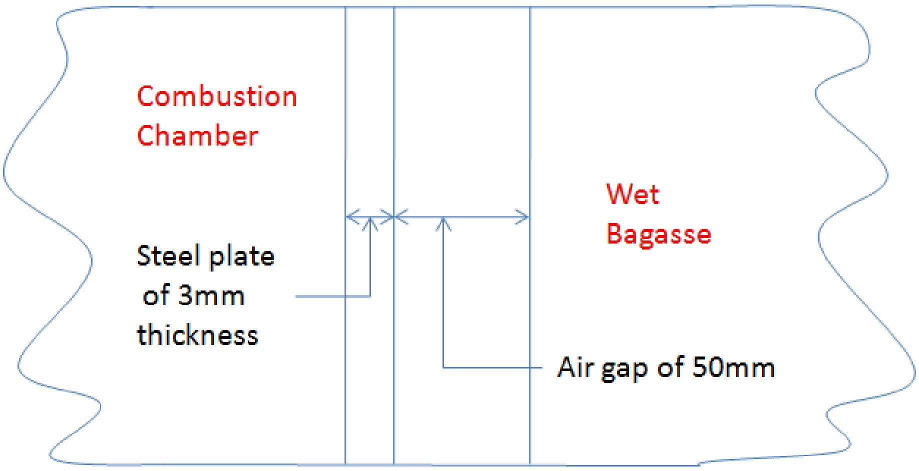

Fig. 2 Combustion chamber and cage for wet bagasse.

The geometry of the plate is having the dimensions of 0.917m*0.917m*0.003m. The number of Nodes and Elements used for meshing are 4802 and 2304 respectively. The boundary conditions for the simulations are heat flux 4800 W/m^2 on the combustion side. This is required to remove the moisture from bagasse as a part of the cycle time. The convective heat transfer coefficient is assumed to be 2 W/m^{2}K on the ambient side of the bagasse packed; based on environmental conditions. Energy scheme of second order upwind is used for the simulation.

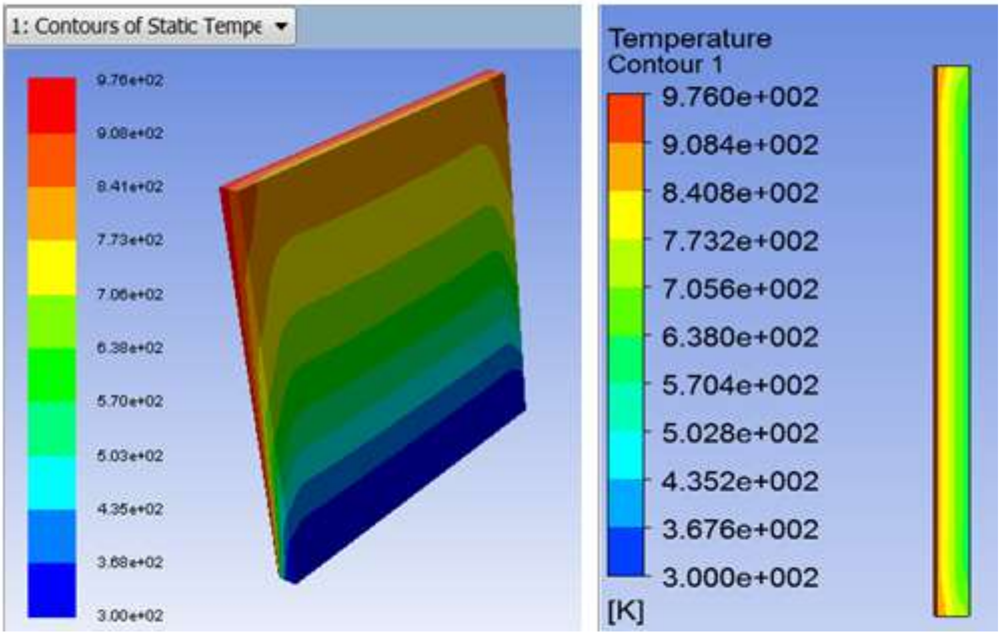

Fig.3 Simulation results of Steel plates of 3mm thickness and an air gap of 50 mm.

The temperature distributions obtained through simulation in ANSYS Fluent are presented in Fig. 3. The values of the temperatures recorded are in the range of 976 K to 300 K. The temperature of steel plate is recorded as 976 K while the temperature of air between the gap of the plate and wet bagasse is varied from 800 K to 300 K. The ambient air comes in contact with the bottom part of the steel plate and gets heated. As the temperature of air increases, it moves in an upward direction and passes through the wet bagasse depending upon the porosity.

III. Experimentation

The test is conducted with a steel plate having a thickness of 3 mm. The experimentation is performed with a perforated steel plate as well as plain steel plate. The dry bagasse is supplied to combustion chamber from the feeder located at front face. Wet bagasse is packed in the cage, surrounding the walls of the combustion chamber. There is a gap of 50 mm between steel plate and bagasse to avoid self-ignition of bagasse as shown in Fig.2. During the combustion, the heat reaches to sugarcane juice kept in juice pan above the combustion chamber. Hot flue gasses are passed through the exhaust pipe. Ash is collected in a tray at the bottom of the combustion chamber. The steel plates get heated during the combustion, the temperature of the steel plate is noted with the help of thermocouple and is around 850 to 950K. The air trapped between the hot plate and bagasse pass through the bagasse which helps to remove the moisture from the wet bagasse. The moisture removal rate is much higher from the combustion side than the ambient side. Hence it is required to change the direction of the cage in order to dry the bagasse from both the side so that effective bagasse drying will take place. The details of experimentation are listed in Table 1.

Table 1: The data related to the quantity of sugarcane and juice etc.

Sr. No	Details of experimentation	
1	Total sugarcane used	134 kg
2	Amount of Sugarcane juice	79 kg
3	Amount of wet bagasse	55 kg
4	The time required for jaggery preparation	2hr 45min
5	The weight of bagasse after the experiment	40 kg
6	Amount of moisture removed	15 kg
7	Average moisture removed.	54.54 %

In the experimentation, 79 kg of sugarcane juice is converted 40 kg of jaggery. The total 57 kg of bagasse is burnt to have its calorific value of 16000 kJ/kg. It means total heat energy available through combustion of bagasse is 912 MJ. The amount of heat energy utilized for the conversion of sugarcane juice to jaggery is 218.9

MJ. Therefore, the thermal efficiency works out to be 24.01 %. The heat utilized to remove moisture from the bagasse is 34 MJ and heat loss through the flue gases, ash and other modes are 658.9 MJ. Considering 50% moisture content in the bagasse the higher calorific value of the wet bagasse is 8893.7 kJ/kg. After the experiment, 54.54% of the moisture gets removed from the wet bagasse. Now the moisture present in the bagasse after drying is 22.73 %. The higher calorific value of dry bagasse with 22.73% moisture content is 15024.22 kJ/kg. Which results in net 6130.58 kJ/kg increased in higher calorific value of bagasse.
The equation used for calculating the higher calorific value of bagasse is:

$$GCV = 196.05\,(100 - W_w\% - W_a\%) - 31.14 W_b\% \quad (kJ/kg)$$

GCV: Gross calorific value.
W_w: moisture present in bagasse.
W_a & W_b: % ash and brix in bagasse respectively considering both as 4 %.

IV. Results And Discussion

The test results are used to analyze heat distribution, percentage moisture removed from wet bagasse and effect on the net increase in the calorific value of bagasse. The temperature of steel plate recorded by thermocouples during the experimentation is in the range of 850K to 950K, whereas the steel plate surface temperature during simulation is 976 K. Temperature deviation is of the order of 25 °C from that of temperature obtained through simulation. The experimental investigation results show that 24 % of the heat is utilized for jaggery preparation, 72 % of the heat is wasted through flue gases, ash and about 4 % heat is absorbed by wet bagasse as shown in Fig. 4.

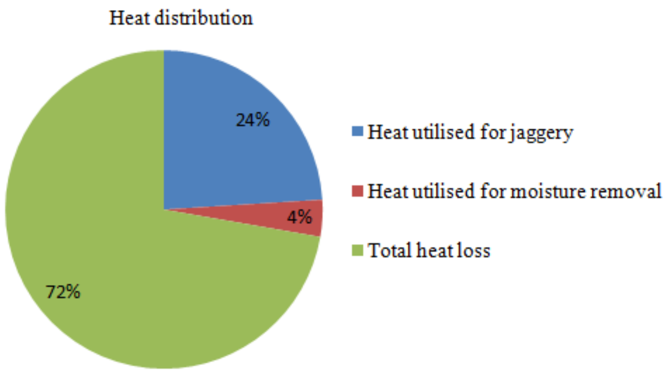

Fig.4. Distribution of thermal energy utilization of the portable jaggery plant

In reality, the jaggery plant with perforated steel plate is operated during which it is observed that the flame reaches to wet bagasse. Therefore it starts burning. In order to avoid such burning a flame, arrester is tried out, which also did not meet the requirement. The variation of moisture removed for different plate types is presented in Fig.5. During experimentation with perforated steel plate, 51% moisture get removed, with a steel plate with a flame arrester 48% and with plain steel plate, 54.54 % of moisture get removed.

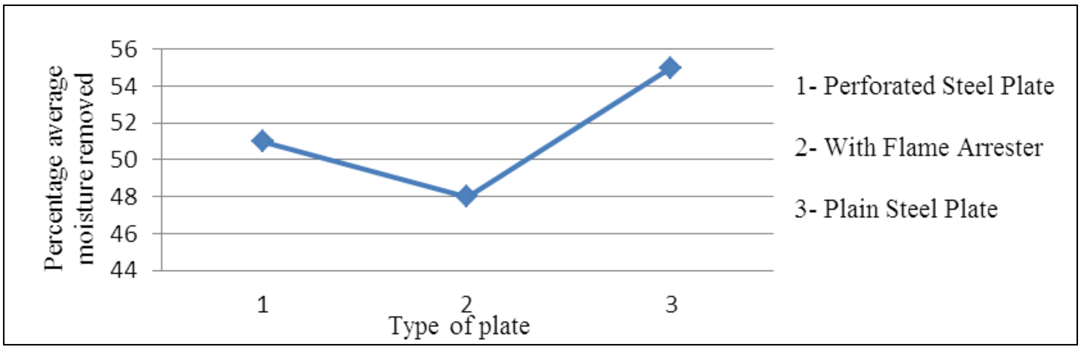

Fig.5. Variation of moisture removed with different plate types

It is observed that moisture removed in a case of plain steel plate is more effective, because of enhancement in the convective mode of heat transfer. The higher calorific value of bagasse is increased from 8893.7kJ/kg to 15024.22kJ/kg in modified jaggery plant due to the heat recovery system, which is higher by 69%.

V. Conclusion

Bagasse drying using heat recovered from the walls of the combustion chamber has been investigated in the present research work. The design and development of modern jaggery plant model experimental performance evaluation of such design manufactured plant is included in this research paper. The following conclusions are drawn from the investigation:

1. The simulation results show that the maximum temperature of the steel plate of thickness 3mm is around 975K.
2. The thermal analysis of the designed jaggery plant clearly indicates the 72% total losses accompanied by the process. The minimum energy required for jaggery processing is estimated to be only 24 % of the total energy supplied.
3. Waste heat from furnace walls can be recovered and utilized to remove moisture content of wet bagasse.
4. The amount of heat recovered by the wet bagasse sample is observed to be 4 % of the total losses.
5. Percentage moisture removal from the wet bagasse sample is observed to be 54.54 %.
6. Net increased in calorific value of bagasse is 69%.

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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