Design & Thermal Analysis of Modern Jaggery Plant with Bagasse Drying Mechanism Using Waste Heat Recovery

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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 rainy season, conventional bagasse drying is impracticable due to unavailability of intense sunlight. Also use of alternate fuels such as wood, automotive tyres, petroleum products etc. is uneconomical and non-ecofriendly. This paper presents the design and development of modern jaggery plant with bagasse drying mechanism using waste heat recovery from the furnace walls. Thermal efficiency of designed plant is found to be 23.67%. Amount of heat recovered by bagasse sample from the walls of furnace is 40.86 MJ. Percentage moisture removal obtained during the test is 66.67%.*

Keywords- Jaggery, Bagasse, Bagasse drying, Heat recovery, Moisture removal

I. INTRODUCTION

Sugarcane is one of the important cash crops cultivated in many parts of India. It is grown as a kharip crop in an area about 49.71 lakh hectares of land. About 3551 lakh tonnes of sugarcane is produced annually with an average yield of 71.43 tonnes per hectare. Out of total sugarcane produced, about 74% is used to prepare sugar, 15% is used to prepare jaggery and remaining is used for other commercial purposes such as seeds, raw juice drinking etc. Jaggery processing is one of the important agro-based industries in many states of India. It is generally a small scale industry providing the local employment opportunities in the rural parts of India. Jaggery has higher nutritional value as compared to white sugar as it retains all the minerals and vitamins found in sugarcane viz. calcium phosphorous, iron etc. Jaggery products are gaining more importance in the diet due to nutritive ingredients they possess.

Almost all the jaggery units employ open earth pan furnaces designed and fabricated by local artisans on the basis of age old skill. Jaggery production mainly involves juice extraction, heating of juice in pan, stirring, clarification, concentration of juice, cooling, moulding and storage. Three roller horizontal crushers having 50-60% crushing efficiency are generally employed for juice extraction. Bagasse is used as fuel for heating of juice. The juice is cleaned during heating and boiling with the use of vegetable and/or chemical clarificants such as bhendi, lime, sodium carbonate etc. After the clarification juice is boiled vigorously till the complete removal of water content it possesses. After the removal of water, temperature of syrup starts rising. When it reaches to the striking point temperature (116 to 1180C) concentrated syrup is removed from the pan and transferred to the wooden or cement trough for cooling. It is then moulded in the desired shapes and packed for disposal.

A jaggery plant mainly requires mechanical and thermal energies for processing. Mechanical energy is required for juice extraction from sugarcane and this juice is converted into jaggery using thermal energy. Cane crushers are operated using electric motors or diesel engines. Bagasse, a fibrous residue left after the sugarcane crushing, is the primary source of heat energy required for jaggery preparation. It is a fuel of varying composition and its calorific value is governed by the calorific value of its constituents. Bagasse mainly consists of water, fibers and dissolved sugar.

Table 1. Composition of Bagasse

Element	Composition
Water	45-50%
Dissolved solids including sugars	2.5-4%
Fibers	45-50%
Minerals	0-0.5%

Calorific value of bagasse is mainly influenced by moisture content in it. Lower the moisture content, higher the calorific value. In conventional jaggery plants wet bagasse is spread over the ground and dried under naturally available sunlight. This bagasse drying technique is time consuming, space consuming and labour intensive. In rainy season, conventional bagasse drying is impracticable due to unavailability of intense sunlight. In such situations, use of bagasse as a fuel is not possible. As a result, jaggery manufacturers have to move towards alternate/extraneous fuels such as wood, rubber tyres, petroleum products etc. Use of alternate fuels such as wood not only increases the production cost but also tend to cause pollution. Thus use of alternative fuel is uneconomical as well as non-ecofriendly. In order to overcome these difficulties alternate ways should be introduced for drying of wet bagasse. Now a days, various bagasse drying techniques are available which in the same time cause high initial investment as well as maintenance cost.

The work presented in this article has following objectives.

- Design and development of modern jaggery plant with bagasse drying mechanism using waste heat recovered from the walls of furnace.
- Examine the thermal efficiency of plant and heat recovery from the furnace walls.

II. EXPERIMENTAL SETUP & PROCEDURE

Modern jaggery plant model is comprised of five main parts namely angle frame with sliding walls, combustion chamber, exhaust duct, pan and side grills. Design and function of each individual part is discussed below.

A. Angle Frame

Angle frame serves as a foundational structure of the plant. All other parts are either fixed or installed upon the angle frame. The frame is manufactured using L-section bars of mild steel. This L-sections are 5 mm thick with 50 mm height and width. Frame structure is enclosed by sliding steel walls.

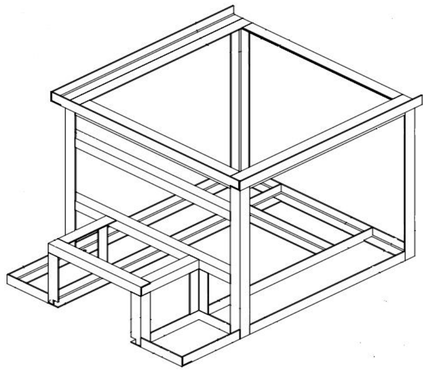

Figure 1. Angle Frame

B. Combustion Chamber

Combustion chamber is an enclosed space of set up in which combustion of fuel takes place along with air. Fuel i.e. dry bagasse is fed to the chamber space through feeding channel. It has two components namely side frame and bottom tray. Side frame of the combustion chamber confines the dry bagasse to combust in a chamber space. Combustion of bagasse takes place on the bottom tray which is provided with perforation. Perforated bottom tray allows self-removal of ash from combustion space.

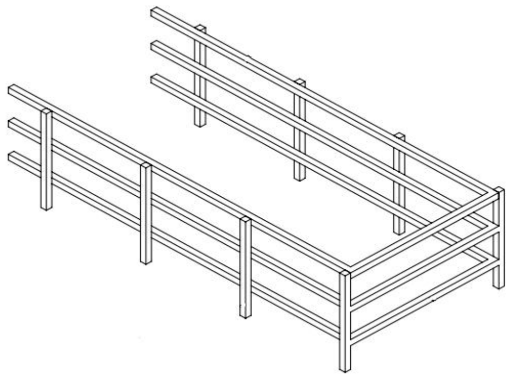

Figure 2. Combustion Chamber Side Frame

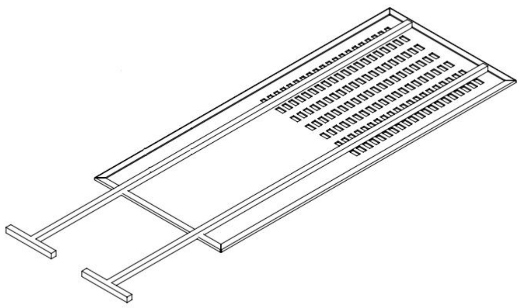

Figure 3. Combustion Chamber Bottom Tray

C. Exhaust Duct

Exhaust duct also called as chimney, is a structure that provides ventilation or passage for hot flue gasses and smoke from combustion chamber to escape to the atmosphere. It is designed and assembled in such a way to provide natural draught that draws combustion air in to the chamber and safely exhaust the combustion gases from combustion chamber. The inside of chimney is kept smooth and changes in cross section directions are kept such as not to restrict the flow significantly.

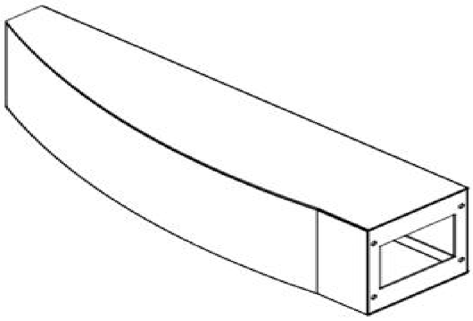

Figure 4. Duct Part 1

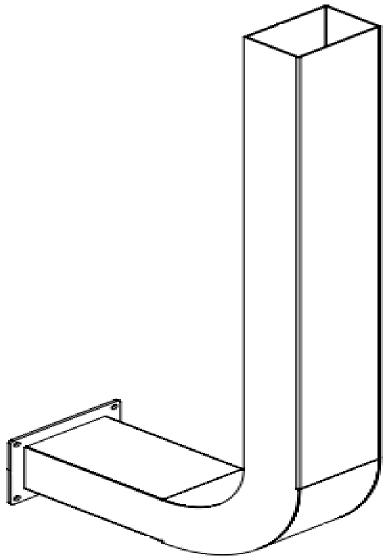

Figure 5. Duct Part 2

D. Pan

Pan also called as kail is a structure in which boiling and concentration of sugarcane juice takes place. It is mounted on the angle frame right above the combustion chamber. Pan is fitted to the structure assembly through hinges for easy movements. Lifting pipes are provided to lift the pan for taking semiliquid jaggery out. Volume of pan is 400 litre.

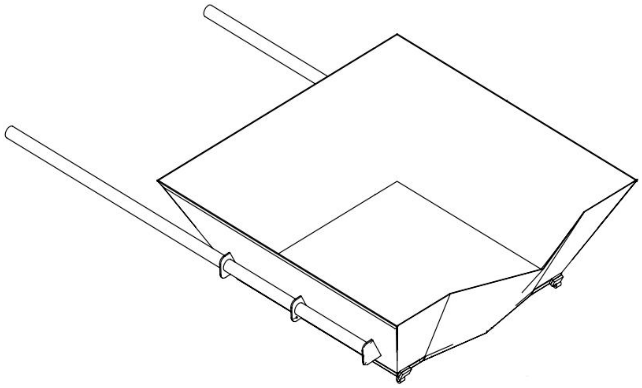

Figure 6. Pan Assembly

E. Side Grills

Grills are the structures in which wet bagasse obtained from sugarcane crushing is filled. These grills are placed around the walls of combustion chamber in order to recover the heat from chamber walls.

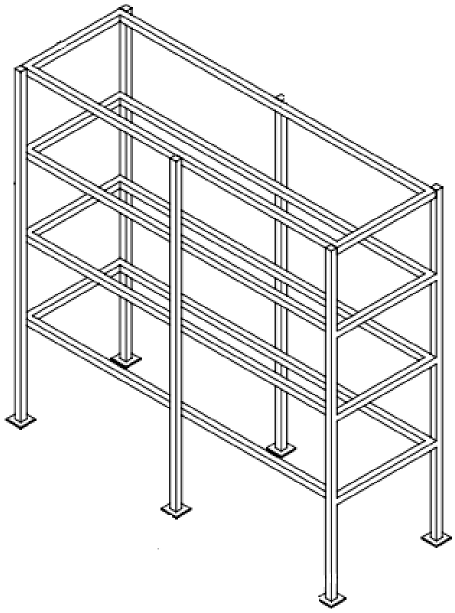

Figure 7. Side Grills

All above parts are connected together to get assembly of jaggery plant. Below figure shows the 3 dimensional model of the modern jaggery plant assembly.

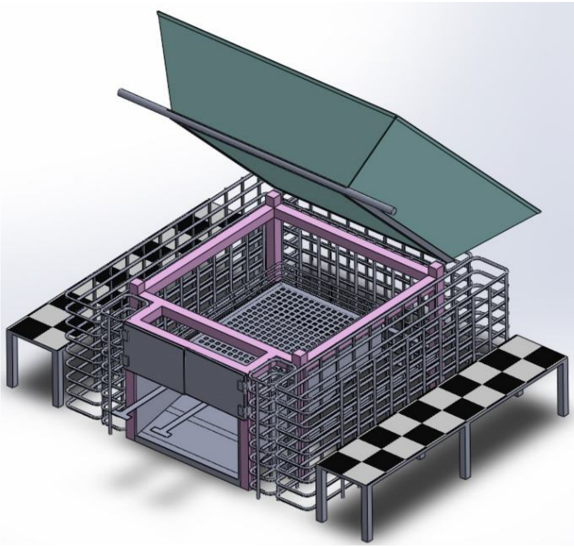

Figure 8. Modern Jaggery Plant Assembly

Figure 9. Photographic Image of Plant

F. Experimental Procedure

Following step wise procedure is used for experimentation:

1) Weighed quantity of sugarcane is crushed using three roller horizontal crusher.
2) Cane juice and wet bagasse obtained during cane crushing are weighted using digital weighing scale.
3) Sugarcane juice is poured into pan and wet bagasse is filled into side grills placed around walls of combustion chamber.
4) Ignition of fuel i.e. dry bagasse into combustion chamber is initiated and weighed quantity of dry bagasse is fed through a feeding channel throughout the experiment.
5) Desired additives (lime, bhendi powder and phosphoric acid) are added into the juice at specific temperatures and molasses is removed from sugarcane juice.
6) After complete removal of water content semiliquid juice is concentrated into the pan till its temperature reaches to the striking point (118o C).
7) Then the semiliquid jaggery is poured into shallow wooden trough and allowed to cool.
8) Then the bagasse sample is weighed at the end of process.

III. PERFORMANCE EVALUATION OF THE PLANT

The thermal performance study is conducted for designed jaggery plant. Analytical calculations were done to find out thermal efficiency of plant and the amount of heat recovered by wet bagasse sample from the walls of combustion chamber. Following assumptions were made for the analytical calculations.

- Calorific value of dry bagasse (with 7 to 8% moisture) is 16230 kJ/kg.
- Theoretical minimum amount of heat required to prepare 1 kg of jaggery (excluding all other heat losses during process) is 10428 kJ/Kg.
- Latent heat of vaporization of water is 2270 kJ/kg.
- Wet bagasse obtained during sugarcane crushing has moisture content about 50%.

Table 2. Measured Parameters for a Jaggery Batch

Measured Parameter	Value
Mass of Sugarcane Crushed, kg	120
Mass of Sugarcane Juice Produced, kg	66
Mass of Wet Bagasse Produced, kg	54
Mass of Additives, kg	0.15
Mass of Molasses Removed, kg	1.5
Mass of Dry Bagasse Burnt as a Fuel, kg	38
Mass of Jaggery Produced, kg	14
Mass of Bagasse Sample after Test, kg	36
Time Required for One Batch, hr	2.5

A. *Calculations*

Heat input per batch,

= mass of dry bagasse consumed × calorific value of bagasse

= 38 × 16230

= 616.74 MJ

Heat utilized for jaggery preparation,

= mass of jaggery prepared × heat required per kg of jaggery

= 14 × 10428

= 146 MJ

Heat lost through flue gases, ash, chamber walls etc. can be found out from heat energy input and heat utilized for jaggery preparation.

Heat lost per batch,

= heat input per batch – heat utilized for jaggery preparation

= 616.74 – 146

= 470.74 MJ

Thermal efficiency of the plant,

$= \frac{\text{Heat utilized for jaggery preparation}}{\text{Total heat input}} \times 100\ \%$

$= \frac{146}{616.74} \times 100\ \%$

= 23.67 %

Amount of heat recovered by wet bagasse sample from the walls of combustion chamber is utilized to remove moisture from it. Amount of moisture removed from wet bagasse sample,

Amount of moisture removed,

= mass of bagasse sample before test – mass of bagasse sample after test

= 54-36

= 18 kg

Percentage moisture removal from bagasse sample,

$= \frac{36}{54} \times 100\ \%$

= 66.67%

Heat recovered by wet bagasse sample,

= amount of moisture removed × latent heat of water

= 18 × 2270

= 40.86 MJ

IV. CONCLUSION

The minimum energy required for the jaggery processing is estimated to be only 23.67% of total energy supplied. Thermal analysis of designed jaggery plant clearly indicates that the process involves heat losses through flue gases, furnace walls, ash etc. Waste heat from furnace walls can be recovered and utilized to remove moisture content from wet bagasse obtained during the juice extraction. Percentage moisture removal from wet bagasse sample was observed to be 66.67%.

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