Review on the Overall Development of Jaggery Plant to Enhance Thermal Efficiency

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ABSTRACT

Jaggery production is a traditional trade of India which provides employment to the people in the villages. India accounts for 70% of total jaggery production. Jaggery has medicinal and nutritional properties that are not present in sugar. The efficiency of the jaggery production process in India is low and the jaggery manufacturer has to bear the loss. As a result, the business is declining day by day. After the necessary changes suggested by various researchers, this efficiency of the conventional plant does not exceed 40 to 48 %. The jaggery production process needs to be improved or changed over time. The main purpose of this paper is to underline the work done by various researchers to date and bring out the resulting benefits and to suggest the necessary changes for the future.

Keywords

Jaggery; Energy analysis; Thermal efficiency; Thermic fluid

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Introduction

Jaggery is an unrefined natural sugar that is produced without adding any chemicals so it has more nutritional values than sugar. India is producing more than 70% jaggery of the total world jaggery production. Jaggery is popularly known as the “medicinal sugar” and is nutritionally comparable with honey. Jaggery contains 60% of sucrose, 7% moisture, and 12% of invert sugar, and also jaggery consists of vitamins, fibers, protein, glucose, minerals, content, etc. Jaggery has a different name in different countries. It’s called Gur in India, Desi in Pakistan, Panela in Mexico and South America, Jaggery in Burma and African countries, Kakuru in Shri Lanka, Naam Tan Oi in Thailand.[1-2]

It has been used as a sweetener in Ayurvedic Medicine for 3000 years. Indian Ayurvedic medicine considers jaggery to be beneficial in treating throat and lung infections. While refined sugar mainly consists of glucose and fructose, jaggery contains glucose and sucrose. But jaggery also has minerals and vitamins which lacks in refined sugar. The mineral content of jaggery includes calcium, phosphorus, magnesium, potassium, and iron and traces of zinc and copper. The vitamin content includes folic. India is a larger producer of Jaggery. At present 24.5% of the cane produced in India is being utilized for producing jaggery. As compared to the total world production, more than 70% of the jaggery is produced in India. Jaggery production is the domestic business in the rural area, which provides employment to the village people at their place. [2]

In the last few years, due to the progress made in the industry, the traditional industries have lagged behind, while some of the industries have closed down due to the non-availability of new techniques in the old industries. As a result, people from the villages started moving to the cities for work. Therefore, it is necessary to save and expand these industries. The jaggery industry provides rural people with the opportunity to work near their homes

Energy is one of the important factors in human life required for agriculture transportation and household application. Thermal power plant contribute around 80% of the total world power generation, which creates air pollution. [3] Sugarcane serves as a green biofuel in a developing countries.[4] Sugar industry is one of the prime candidate for supplying low-cost, non-conventional power via cogeneration and estimate potential for cogeneration is around 3500 MW to 5575 MW. and they emit greenhouse gas which gives sustainable development.[5–7]

The area under sugarcane cultivation is increasing year by year in India. Though the yield of sugar has increased, the production of jaggery is reducing. This is because of declining Jaggery consumption—and increasing sugar consumption.[8]

Although there are three types of jaggery production plants in the market, small, medium, and large plants, the initial investment is high, the profit from plant is higher than that of medium and small plants. An investment made in a large plant pays off in a short period of time.[9]

India’s export statistics of jaggery and confectionery for the last five years. From time immemorial, India has been known as the world's largest producer of jaggery. India alone accounts for 70% of the world's total income, so it is important to save and grow this industry. If India exports jaggery and other products based on it annually, it provides financial support to India. In the year 2018-19, India has exported 3,13,822.78 MT of Jaggery & India Earn Rs. 1,606.07 crore.[10]

Table 1. The details of Jaggery export quantity and earning [10]

Year	Qt in MT	Value in Rs. Crore
2014-2015	2,58,252.71	1,161.81
2015-2016	2,92,841.15	1,290.23
2016-2017	2,97,680.36	1,467.97
2017-2018	2,52,142.83	1,380.36
2018-2019	3,13,822.78	1,606.07

In the last six years from 2014-2015 to 2019-2020 Maharashtra, Gujarat, Tamil Nadu, Rajasthan, Uttar Pradesh, and Karnataka are the six leading states in jaggery exports accounting for 90% of total exports as shown in Fig.1Maharashtra and Gujarat account for the lion's share. 40% is exported by the Government of Maharashtra and 30% is exported by the Government of Gujarat. Out of this, Maharashtra gets Rs 3610 crore and Gujarat gets Rs 1614 crore as shown in Fig. 2[11]

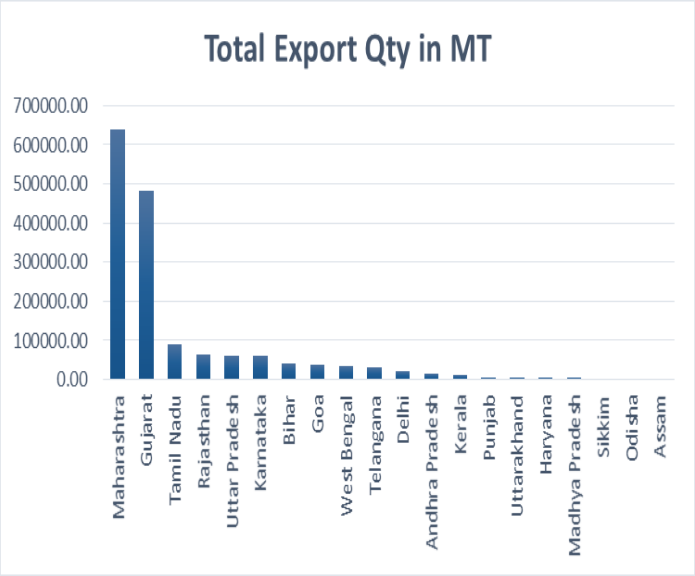

Fig. 1. State wise total jaggery export quantity in MT [11]

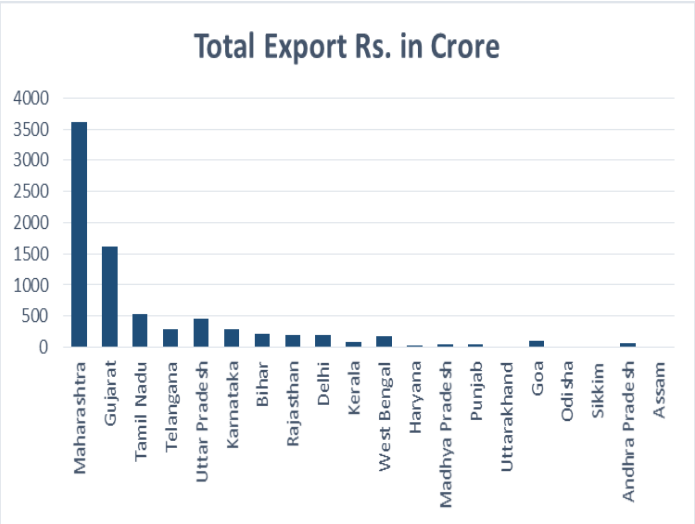

Fig. 2. State wise total jaggery export cost in Crore [11]

Jaggery Manufacturing Process

The jaggery manufacturing process is divided into three main parts. It consists of effective crushing of sugarcane for extraction of juice, filtration and heating of juice for concentration and finally cooling and solidification of concentrated juice to form required shape jaggery block.

Crushing: Juice extraction through crushing is the first step in jaggery manufacturing. Sugarcane is squeezed in three iron rollers cane crusher with very high pressure, which can be placed vertically or horizontally. The efficiency of crusher ranges from 50% to 60%. Complete extraction of juice is important to get more recovery of jaggery. So multi pass of cane is required to get maximum extraction of juice. Splashing hot water during crushing and multiple crushing enhances the efficiency up to 80%. Jaggery farmers do not prefer this method due to additional energy requirement for hot water and the evaporation of water during the boiling process. During the crushing process, wet bagasse is generated as a by-product. After drying this bagasse, It is used as a fuel for the furnace.[12]

Juice Filtration & Concentration: Extracted juice is firstly collected in the masonry settling tank which is available in the ground. The juice is first filtered in this tank using cloth to separate out the cane particles from the juice. This juice is further transferred to an iron open pan through a pump for boiling purpose. An open pan is mounted on the furnace for heating purpose. Bagasse generated during the crushing process is used as a fuel for the furnace. Complete combustion of bagasse in furnace and effective transfer of heat to pan through flue gasses causes a concentration of juice.

During the boiling process scum present in the juice is removed by adding a clarifying agent. Lime is added during the boiling process to maintain the pH around 6.0 to 6.4. The quantity of lime depends on the quality of sugarcane. Lime helps the jaggery making process by increasing the rate of crystallization of sucrose but excess use gives an impact on colour darkening.

Nowadays, in the market two types of clarifying agents are used during jaggery making viz., chemical and natural clarificant. Hydros, super-phosphate, phosphoric acid, chemiflocks, and alum are used as chemical clarificants. Use of these depends on the quality of juice as they may function as a bleaching agent, electrolyte, or pH adjusting agent. Vegetable clarificants like mucilage's of bhendi, chikani, kateshevari, etc. were used as a natural clarificants. The amount of additives quantity used is 30 to 50 gm. / 100 kg of juice. [13] Now a days, the use of natural clarificants is encouraged due to the problems in exceeding the permitted level for chemical clarificants. [12]

Cooling and Molding: Brix is the percentage of sugar in juice. When the Brix value of concentrated juice is reached up to 85 % Bx to 92% Bx, it is taken out of the fire and released on the cooling pit. In cooling pit juice temperature is reduced from 120^0C to 76^0C using natural convection. For further solidification concentrated juice is filled in the wooden, aluminum or earthenware pot. Shape and size of these pots depend on the market demand. Rectangular shape, bucket-shaped and trapezoidal shapes are most demanding in the market. Nowadays jaggery powder is also a good alternative solution for solid jaggery because it is more convenient to use in today's hectic and fast life. [12]

Packing and Storage: Shelf life of jaggery depends on moisture content in the air and temperature condition in which it is stored. For longer shelf life moisture content in the jaggery should not exceed more than 6%. In India near coastal region and in rainy

season humidity level is more so it affects the shelf life of jaggery. In India from January to May, average temperature is more and the relative humidity is less as compared to the month of June to December. So, moisture migration rate from the atmosphere to jaggery is very less which enhances the shelf life of jaggery in this month. Life of solid jaggery stored at low temperatures is more than one year. Packing of jaggery is also one of the important factors in shelf life. Jaggery packed under nitrogen and vacuum environment have a better life than polythene bags [14-15]

Jaggery Manufacturing Technique

Jaggery is made after extracting water from the juice of sugarcane. Water can be extracted in two ways, one by evaporation and the other by freezing. In India, jaggery is made everywhere by the evaporation method. Evaporation is a well-known and easy method and is prevalent everywhere. Water can also be extracted from sugarcane juice by the freezing method. As shown in Fig. 3, various researchers have studied this method and are learning their advantages and disadvantages. [16-17]

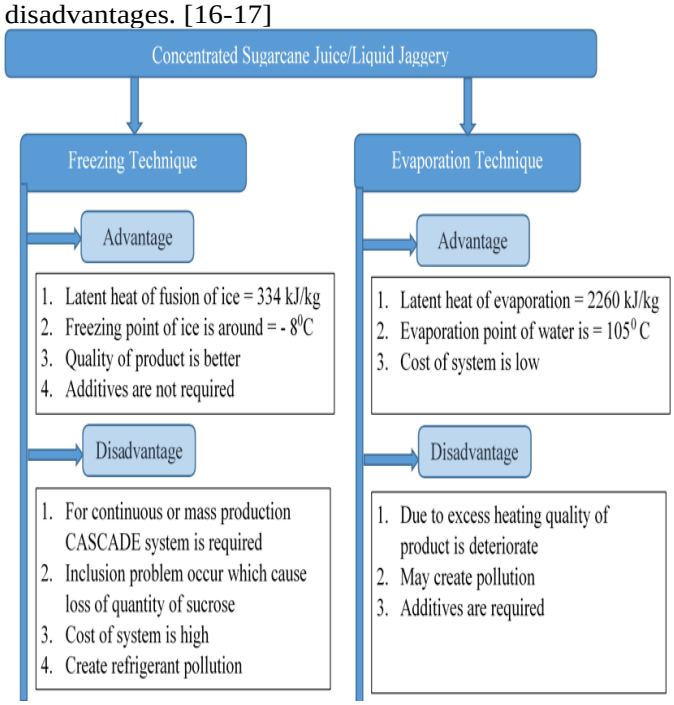

Fig. 3. Comparison of concentration techniques

A. Evaporation Technique

In India most of the plants work on Evaporation Technique. There are four types of evaporation technique plants through which jaggery can be manufactured

a. Open pan clarification + Open pan evaporator + Open pan crystallizer (Using furnace).
b. Open pan clarification + Evaporated body + Open pan crystallizer (Kadai) (Using steam boiler).
c. Open pan clarification + Vacuum pan (Using steam boiler).
d. Open pan clarification + Open pan evaporator + Open pan crystallizer (Using thermic fluid heater).

B. Types of processes of jaggery production [18]

a. Single pan process (Kolhapur type)
b. Two pan process (UP type)
c. Four pan process (UP type)
d. Closed pan (Multiple effect evaporator)

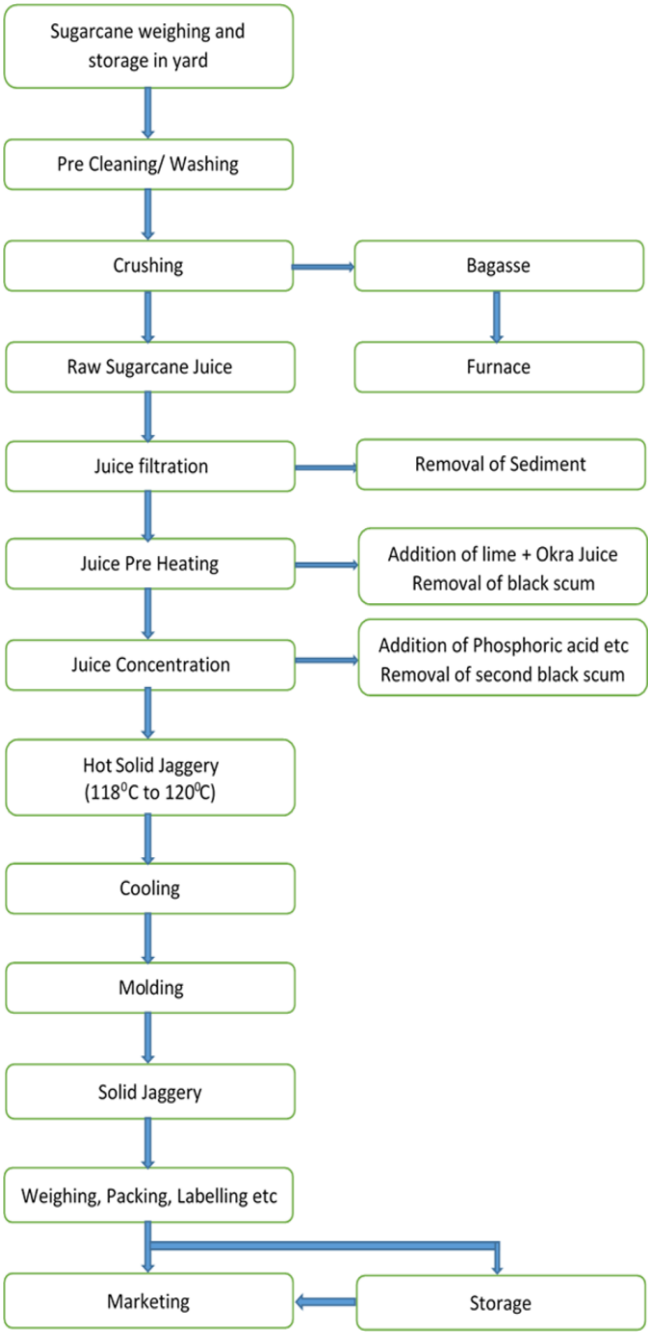

Fig. 4. Process flow chart for solid Jaggery

Factors Affecting The Thermal Efficiency Of Plant

Conventional single pan process plant, efficiency of this plants is very low up to 15 % to 19 % only.[19] To enhance the efficiency of the plant different researcher are focusing on modification of existing plant. Conventional Plant is divided in to three parts generation of heat through combustion of bagasse in furnace, transfer of heat to the pan through flue gasses

and last is the releasing of flue gasses in to atmosphere through chimney.

To enhance the efficiency of the plant complete combustion of bagasse is required in furnace. Maximum heat should be transferred to the pan through flue gas and finally there should be minimum wastage of energy in the form of stack losses.

Jaggery plant efficiency firstly depends on efficient crushing mill. As per the research it is stated that every sugarcane contains around 65% to 70% juice and remaining 30% to 35% is wet bagasse. So jaggery recovery depends on efficiency of crushing mill. [20]

Sardeshpande et al. [20] carried out a test on four pan jaggery unit for energy analysis during furnace batch operation. In jaggery manufacturing, only 813 MJ/h energy is required out of 2846 MJ/h. Rest of the energy is wasted in the form of stack losses, wall heat losses and heat carried in ash. Energy balance equation indicates that only 29% of the total energy supplied through bagasse combustion is required for the jaggery manufacturing process. [20]

Process chart in Fig.5 shows the factors affecting the thermal efficiency of the plant

Group A

a. Moisture removal from the bagasse before used as fuel in furnace [21]
b. Optimum fuel feeding to furnace [22]
c. Controlled Feeding rate to furnace [20]
d. Installation of damper at air inlet of furnace [16]
e. Preheating of air before furnace [21]
f. Size of combustion chamber [23], [24]
g. Changing material of furnace from normal bricks to fire bricks cemented with refractory cement instead of earthen clay [22], [23]
h. Cast iron fire grade provided in the furnace [22]
i. Optimized air entry ports in the furnace [22]

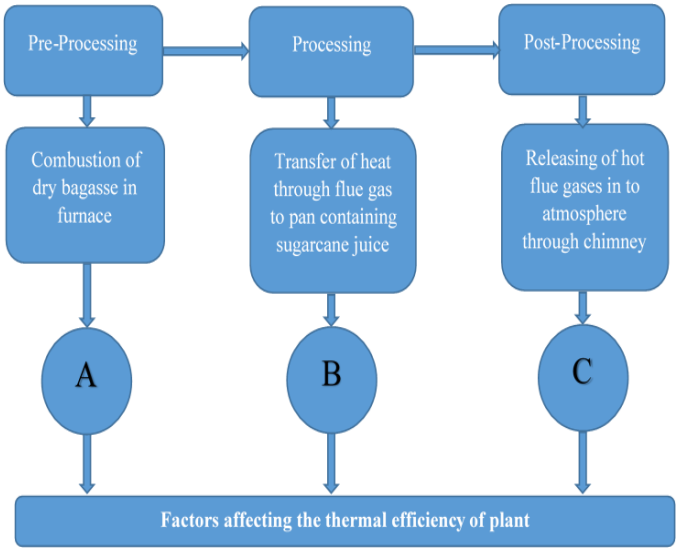

Fig. 4. Factors affecting the thermal efficiency of the plant

Group B

a. Extraction of more sugarcane juice from sugarcane using double or triple pass roller instead of single pass roller [22]
b. Cluster of freezing and heating technique. [16]
c. Conversion of single pan to two pan [25]
d. Conversion of single pan to two pan with fins at the bottom of pan [24]
e. Number of pans and size of pans [24]
f. Multi pan concept [22]

Group C

a. Size and geometry of flue gas channel [24]
b. Conversion of rectangular cross section of chimney in to circular cross section. [22]

Height of chimney, provision for air supply [24], [26]

Table 2. Technological modification on operational conditions of jaggery manufacturing plants.

Sr. No.	Researcher	Year	Description	Remark
1	Rao et al.[27]	2003	Analyzed the one tonne sugarcane batch for jaggery making and calculated the thermal efficiency of plant	In one tonne sugarcane crushed batch, 650 lit juice is extracted and remaining 350 kg wet bagasse is formed. Where after sun drying wet of bagasse reduces up to 250 kg and required bagasse is 500 kg. So additional 250 kg bagasse required per batch which is burden for jaggery manufacturer
2	Madan et al.[22]	2004	Focused on modification of existing plant which is feasible and cost effective for rural environment	By modifying proper design of the furnace and chimney which result in to enhance the combustion performance of bagasse. To achieve this fire grates along with optimized air entry ports has been provided in to furnace for proper mixing of air. In conventional plant normal masonry bricks cemented with earthen clay is replaced with fire bricks cemented with refractory cement to enhance the life and performance of furnace. By doing all these modifications gur production rate per day (14 hrs.) is increased by 20%.
3	Rane et al [16]	2005	Developed new technique of jaggery manufacturing. Researcher made the cluster of freezing and heating technique to save the energy.	Freezing technique is used to concentrate sugarcane juice up to 40 Brix. Energy required for freezing is much lesser than the heating causes energy saving.
4	Singh et al.[25]	2009	Analyze the overall efficiency of furnace for two pan jaggery unit over single pan jaggery unit.	Efficiency of single pan jaggery unit is about 16 % to 19.7 % whereas for two pan jaggery unit gives efficiency up to 29.3 %, causes minimizing stack losses

				present in the single pan unit.
5	Sardeshpande et al.[20]	2010	1. Studied the performance of a four-pan jaggery plant. In conventional plant fuel feeding to the furnace is not controlled so incomplete combustion occurs cause very less thermal efficiency of the plant due to which manufacture need to purchase bagasse or other fuel from market. 2. Installation of damper at the air inlet of furnace is required to avoid convective cooling of furnace during non-firing period by closing air inlet.	1. By controlling fuel feeding rate causes reduction in specific fuel consumption from 2.39 kg bagasse/kg jaggery to 1.73 kg bagasse/kg jaggery. 2. Result of all this work, stack losses present in the conventional system get reduced.
6	Anwar[24]	2010	To enhance the heat transfer from flue gasses to sugarcane juice through pan, fins are attached at the bottom of the pan	Result of this 31.34% bagasse become saved and the process time of jaggery making is reduced from 165 min to 105 min i.e.36.36%
7	Sahasrabudhe et al. [28]	2011	A mathematical model is developed that helps in analyzing the effects of various system parameters on ice growth and subsequent juice concentration	Very useful to estimate the effects of various system parameters on ice growth and subsequent juice concentration without carrying out operation
8	Arya et al.[23]	2013	Focused on design modification of existing three pan plant. Plant, made with fire bricks, fire grates, improved chimney and dampers	Sugarcane processing capacity has been increased by 16.67 % per shift causes 23% additional jaggery manufacturing and 12% bagasse saving
9	Sharon et al.[12]	2013	Conducted test on traditional jaggery unit and analyze the process of jaggery making.	Traditional jaggery unit used single tandem crushing roller having efficiency is 60% only which can be improved by sprinkling hot water on crushing sugarcane and efficiency of furnace is very low up to 14.75%
10	Manjare et al [29]	2013	Works on the concept of reutilization of flue gasses for preheating of juice and air before releasing in to atmosphere through chimney for single pan.	By raising the temperature of juice by 35^{0}C before pouring in to the pan, causes improved the thermal efficiency from 16.16% to 24.36% and bagasse consumption is reduced by 1.2 kg per kg jaggery production.
11	Anwar. [30]	2014	Design and developed a model of furnace efficiency booster for creating turbulence below pan	Enhanced thermal efficiency by 35%, 26 % bagasse is saved during the process and 30% processing time get reduced.
12	Shiralkar et al.[26]	2014	Analyze the performance of two single pan jaggery unit of different chimney height by varying the mass flow rate of air. Also conducted test on four pan jaggery unit	Efficiency of both the plant is very from 53-76% and 50-57% respectively by varying the air flow rate for both the unit. Maximum efficiency in both units were obtained by blocking excess air
13	Agalave[31]	2015	Conducted the trial on modified single pan unit. Parallel fins and baffles are connected at the bottom of the pan.	Thermal efficiency of the plant enhanced by 9.44% compared with traditional furnace, and causes 31.34 % bagasse saving
14	Santhy et al [32]	2015	Analyze the economic impact of multi pan plant over single plant in jaggery preparation	Due to multi pan concept process time for batch get overlapped causes more production of jaggery per day also enhance the plant efficiency due to reduction in stack losses
15	Kavatkar et al.[33]	2015	Analyze and developed sugarcane feeding system to increase the overall efficiency of plant	Automatic fuel feeding system save human efforts, no of labours and avoid safety hazards.
16	Jakkamputi et al [21]	2016	Studied the use of solar energy for re-heating of the sugarcane juice, drying of bagasse and inlet air of jaggery furnace	Use of solar energy for re-heating of the sugarcane juice, drying of bagasse and inlet air would increase the efficiency of jaggery plant.
17	Rane et al [17]	2016	Conventional jaggery plant consumes all bagasse or most of the time required extra bagasse for water removal from sugarcane juice through evaporation process. Also due to uncontrolled heat during process create hot spot causes caramelization of jaggery. Result of this quality and taste of jaggery gets deteriorate. To overcome this problem alternate method need to adopt. Freeze concentration technique is used to remove water from sugarcane juice in the form of ice.	It also solve the problem of caramelization causes improve the quality of jaggery and saving of bagasse up to 77% of produced bagasse. It gives additional revenue generation to farmers or jaggery entrepreneurs. Problem associated with this system is loss of sucrose due to inclusion and cost of system
18	Madanrao, et al.[34]	2017	Analyzed the performance of modified integrated fins at the bottom of single pan furnace over conventional single pan	Thermal efficiency of plant is increased by 9.15% and bagasse consumption is decreases by 28.19%
19	Kulkarni et al [35]	2018	Studied and compared result of numerical simulation of heat transfer phenomena in the open heat exchangers with field measured data.	Allows to analyze system performance and scope for improvement

Table 3. Survey of design development in jaggery plant

Sr. No.	Types of plant	Remark
1	Single pan Jaggery plant [19, 25, 27, 29, 35]	Efficiency of this plant varies from 14% to 20%
2	Double pan Jaggery plant [25]	Overall efficiency of the furnace was found to be 25%
3	Double pan with fins to the bottom of the pan [24]	Overall efficiency is improved up to 29% as well as cycle time is also improved from 150-165 min to 105-120 min which increased the production rate
4	Four pan jaggery plant [20, 36-37]	Maximum utilization of heat take place in such plant so that overall efficiency of such plant is increased up to 50 % by controlling fuel feeding rate to the furnace
5	Single pan jaggery plant using solar energy [21]	Solar energy is used for pre-heating sugarcane juice, drying a bagasse and for preheating of air. 2360.44 kJ of heat energy & 0.23604 kg of dry bagasse could be saved per kg of jaggery preparation. If inlet temperature of air is increased up to 1500C, 1988.48 kJ of heat energy & 0.12252 kg of dry bagasse can be saved per kg of jaggery preparation.
6	FCT of sugarcane juice in a jaggery making process [16]	FCT is used to concentrate sugarcane juice from 20 Brix to 40 Brix. Bagasse saving of about 1338 kg per day can be achieved also increase the quality of jaggery by reducing inversion of sucrose. Drawback of system is that quantity of jaggery get reduced.

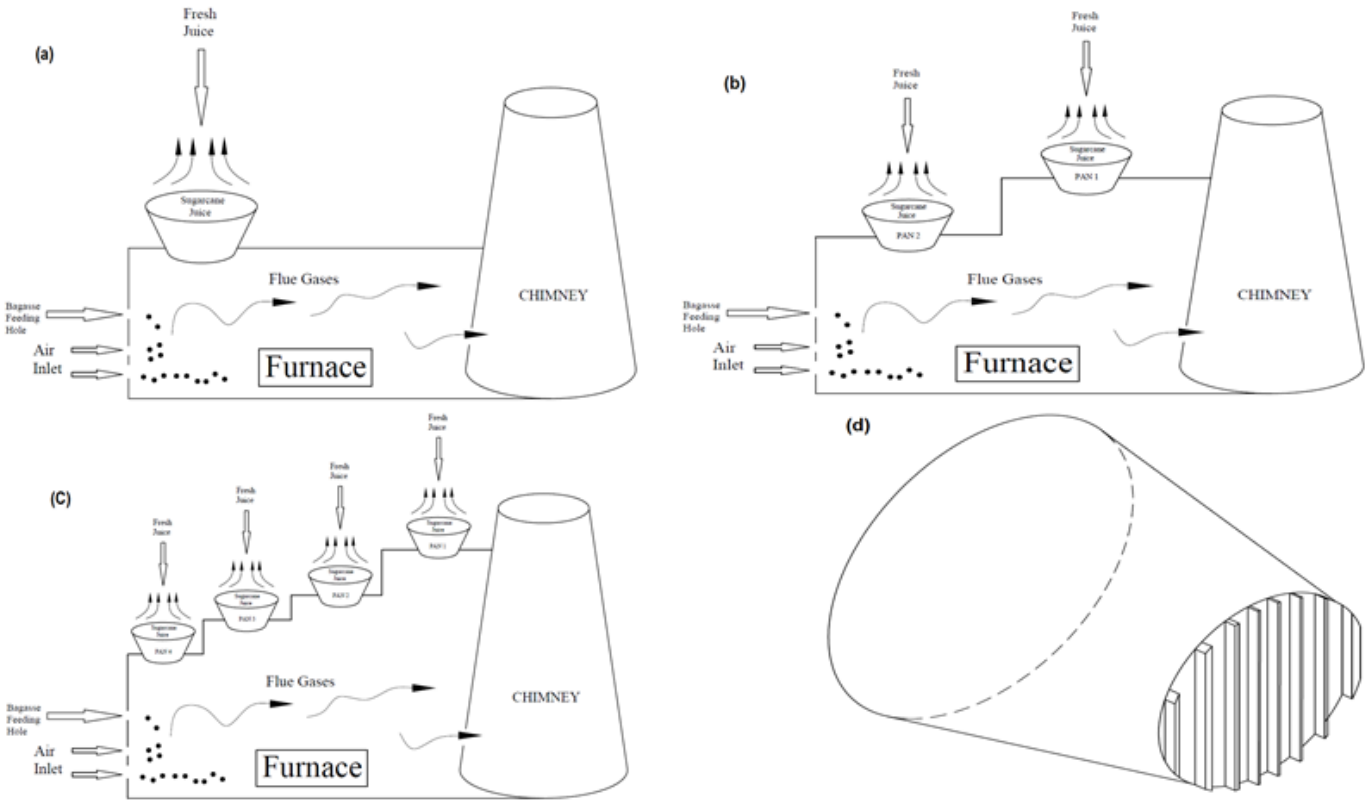

Fig. 6. Arrangement of pans in jaggery plant (a) Single Pan (b) Two pan (c) Multi Pan (d) Pan with fins at the bottom

Summary

For the overall development of the conventional plant, researcher need to focus on all three parameters i.e. combustion of dry bagasse in furnace, effective transfer of heat through flue gases to the pan containing juice and releasing of hot flue gases in to atmosphere through chimney . Only then jaggery entrepreneurs will get more profit by exporting good quality jaggery all over the world and will better the livelihood.

There is a need today to modify the prevalent methods of jaggery production. Traditional kilns are still used in India for jaggery production which have very low efficiency. Various researchers have worked on this and have done research to increase its efficiency. Modifications suggested include:

1. Using a multi pan system
2. Provision of fins to enhance heat transfer

3. Use if firebricks in furnace instead of earthen bricks
4. Optimizing chimney height
5. Optimizing size and shape of the chimney
6. Controlled feeding of fuel in the furnace
7. Use of solar energy for pre-heating of juice

However, even today its efficiency is not more than 48% so new methods need to be adopted.

To minimize the stack losses, effective utilization of hot flue gases is necessary. This can be achieved partly by using the flue gases for controlled heat transfer during the entire jaggery making process. This will enhance the thermal efficiency of the plant. [38], [39]

Another possible method to increase the thermal efficiency is to use an efficient heating arrangement. This method replaces the traditional furnace and uses a thermic fluid heater in its place. The efficiency of a thermal fluid heater is about 70%. This thermic fluid heater is surrounded by insulation on all sides so there is very less wall heat losses and most the heat generated in the heater is given to the thermic fluid. So the fuel required for combustion purpose in thermic fluid heater is relatively less.

These thermic fluids are a petroleum-based stock and have very good resistance to degradation at high temperature range. This hot thermic fluid flows through the pipe. All the pipes are surrounded by insulating material so the loss of heat energy from the liquid is greatly reduced. The bottom of the sugarcane juice pan is surrounded by these pipes and the hot fluid flowing through it gives energy to the liquid juice so the energy loss is relatively very low.

The liquid with low energy is pumped back into the thermic fluid heater. So, in second cycle it took very little energy to heat these liquids because the system works in a closed system. Therefore, the bagasse requirement in this modified system is very low. This causes relatively less environmental pollution and the surplus bagasse can be sold in markets to get additional income. Overall it will help to improve the livelihood of jaggery manufacturer.[40]

Nomenclature

Br	Brix in %
FCT	Freeze Concentration Technique
MT	Mega Tonne
kJ	Kilo Joule
kg	Kilo Gram

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