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Technologies for Preparation of Solid and Granular Jaggery: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author EKK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PVKJR and DK managed the analyses of the study. Author SP managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Jaggery is unrefined sugar used in all countries of the world under different names prepared from sugarcane juice. It is a tastemaker and color maker rather than being just a sweetener. Jaggery is rich in minerals and vitamins contained more than of refined sugar. Nowadays people are very conscious about health and current food consumption. People are concentrating mainly on high-quality foods with low capital investment. Jaggery is one of the products which is cheaply and easily available to all categories of people. To meet market demand and jaggery export, with a short period of production though it is consumed throughout the year, the high quality and hygiene jaggery can be prepared by increasing the plant efficiency by considering the modifications in the design of the furnace, pan, rate of bagasse consumption, rate of heat transfer from hot flue gases. The production can also be increased by practicing good manufacturing practice (GMP), by preparing other products like liquid jaggery and granular jaggery in addition to solid jaggery. This paper discusses the various up-gradation technologies of jaggery preparation and besides, this paper gives an overview of various forms of jaggery preparation from different sources of input along with automation and advanced jaggery making process.

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1. INTRODUCTION

Jaggery or Gur is sticky brown to golden yellow, coarse, unrefined and non-centrifugal sugar obtained by evaporation of sugarcane juice. Jaggery is considered as "Healthiest sugar" or "Specially sugar" because it has the highest medicinal and nutritional values with inherent taste and aroma (FAO, 1994). Jaggery is the most nutritious and best nutraceutical agent and per capita consumption of jaggery is 8.1 kg, whereas sugar is 14.2 kg respectively. Jaggery and sugar is produced mainly from sugarcane (70%) and other sources of palm trees (palmyra, date, sago and coconut) of about 30% [1].

Jaggery making is one among the main agro-processing industries found in rural India which runs on small investment or by a group of farmers providing 2.8 million employment to rural youth. As the sugar factories are running in losses it may not possible for factories alone to meet the total demand for sweeteners with an increase of population [2].

2. JAGGERY MAKING PROCESS

Jaggery manufacturing consists of different process units like juice extraction, juice clarification, juice boiling for concentrating, and juice cooling followed by molding and storage. Jaggery manufacturing process depends on:

(1) Method of boiling like (a) Open pan boiling method-Traditional method (b) boiling juice with Steam - a semi-automated process and (c) boiling of juice in a vacuum pan evaporator – an advanced automated method.
(2) Ultimate form to be produced like solid jaggery, liquid and granular jaggery.
(3) Sources of input (Raw material) like from sugarcane, date palm, palmyra and toddy palm and from other sources like sago, coconut etc.
(4) Pre and post-harvest conditions of cane.

2.1 Traditional Method

2.1.1 Open pan jaggery making

2.1.1.1 Juice extraction (or) collection of juice

Juice extraction is the 1st operation in jaggery production. The juice extraction from sugarcane juice using a simple mechanical device popularly known as crusher. It consists of 3 rollers oriented either in horizontal or in vertical position popularly known as Horizontal or vertical crusher. In recent days four roller crusher also exists completely made of ss for small scale entrepreneurs. In olden days juice extraction for jaggery making is done by manual or pair of bullocks or buffaloes. Nowadays manual and animal-drawn crushers are replaced by motorized crushers run either by electricity or by using fuel [3]. On every feeding of 3-4 canes into the crusher, the expelled juice is collected into a masonry settling tank to separate the suspend the particles [4]. The light and heavy particles are filtered with a muslin cloth, fine cloth (or) by wire mesh. The clear juice is drawn off from one side of the outlet of the tank and transferred to the boiling pan.

On Cushing one tonne of sugarcane yields 650 kg of juice which is about 65 to 75% and 350 of bagasse (50% mc on wb), the bagasse was dried to obtain 245-250 kg dried bagasse [5].

2.1.1.2 Juice boiling and concentration

In traditional method gur or jaggery was done with the help of a skilled person who has sufficient knowledge and experience. The juice collected in the boiling pan is made of 20G round bottom made with thin galvanized iron (GI), mild steel or aluminum sheet, filled up to 1/3 of the capacity of the pan. Boiling of sugarcane juice is the 2nd important step in jaggery making process. Boiling of juice is done by using bagasse obtained after crushing of cane which is dried either in sun or in a rotary drier having a moisture content of 20% [6].

2.1.2 Furnace

Dried bagasse, sugarcane leaves, and trash was burnt near the inlet of the furnace. Calculation shows that 0.65 kg of bagasse is consumed for the preparation of 1 kg of jaggery [7]. A person at the inlet continuously supplies the material and monitors the burning of the flame in coordination with jaggery preparation person. The ash was removed from the furnace with the help of specially designed tools after each batch of jaggery making which is manure in the sugarcane fields.

2.1.3 Description of the furnace

Many types of jaggery making furnaces have been developed in India. An improved version over furnace of Godavari-sindhwati was developed at Anakapalli having a top diameter of 234 cm, Height 92 cm, and bottom diameter of 165 cm. It has a small inlet trough which fuel was fed and on the other end, an outlet is present for the removal of exhaust gases. The furnace was constructed in a north-south direction as per the direction of the wind to increase burning efficiency. The furnace facilities uniform boiling due to the positioning of two grates (Vertical and Horizontal) and one central wall in the furnace [6].

2.1.4 Pan

Pan used for jaggery making are of various types based on the shape (Round, square and Rectangular), size (Small and Big pan), and on a number of pans like (single pan, double pan, 3-pan and 4-pan or multiple pans) and based on the constructional feature (pan with fins and pan shaped pits made with cement).

2.1.5 Description of pan

Open pan of smaller size has a diameter of 5 feet or 152.4 cm, which holding capacity of 200-300 kg of juice made of mild steel, GI or aluminum sheet. Bigger size pan holds a diameter of 240-270 cm, depth below 45 cm which holds 400-500 kg of juice [8,9]. Depending on the size of the pan the size of the furnace also varies from place to place. Mostly round shaped pan is used by farmers. Nowadays as per FSSAI pan made SS 304 grade material is used by big-scale entrepreneurs.

2.1.6 Clarification and clarificants

This is the process in which impurities are removed from sugarcane juice. Clarification of juice during boiling is accomplished by adding lime [$Ca(OH)_2$], CO_2, or phosphoric acid that acts as a complexing agent and forms scum. The scum is removed periodically. The addition of lime simultaneously increases the p^H of fresh juice from 5.2 to 5.4 to 6.0 to 6.4 [10,11]. While preparation of jaggery from overmatured cane (in which sucrose content is low and decreases due to inversion) addition of lime improves the consistency of jaggery, if more lime is added darkens the color of jaggery also.

2.1.7 Dosage

For every 100 kg of juice (i.e 1 kg of lime is mixed with 4 liters of water) in an appropriate proportion of 60-70 ml of lime milk solution is added.

2.1.8 Vegetative calrificants

Mucilage of bendi (okra), chikan, guar gum, kateshvari, moringa leaf extract, lemon juice, honey, and aloe vera are used as vegetative clarification concern with health hazards [12,10,13].

2.1.9 Chemical clarificants

Chemical clarificants namely hydros (or) sodium hydrogen sulfite which is a chemical clarificant which is widely used. Other chemicals like sodium carbonate, calciumhydroxide[$Ca(OH)_2$], Superphosphate, phosphoric acid, chemical flocks and alum are bleaching or chemical clarificants [10,12,13]. The clarificants function as bleaching agents, electrolytes and p^H adjusting agents.

Many times jaggery has been found to contain excess quantity of harmful chemicals, which affect the taste and storability of such jaggery samples. Jaggery samples prepared by farmers use chemicals for color to attack buyers which contain a dosage of more than 80-120 ppm of sulphur dioxide which are well above the prescribed norms of government i.e, 50 ppm by Indian standards (IS 12923): 1990. Nowadays because of health-conscious, people used to buy chemical-free jaggery (Organic jaggery). The cost of organic jaggery i.e, jaggery prepared by organic manner is 25% more than jaggery prepared by inorganic manner (chemical clarificants).

There is a growing demand for organically produced jaggery both within the country and in the export market. The response surface method suggested that 77.5ºC temperature, 1.5 mm thickness of charcoal were efficient to optimize the clarification process [14].

2.2 Boiling

The main objective of boiling is to concentrate the juice to make solid form jaggery or to make thick syrup (Liquid Jaggery) to increase the self-life of juice. During this process, several physical and chemical changes occur, which are closely monitored by a skilled worker. Overheating may lead to dark color product with bitter taste. After the addition of lime to adjust the P^H the juice should be boiled in a pan for about 2 hours by removing scum from time to time. It was estimated there was a loss of juice of about 30-40% through scum during jaggery making. The boiling of juice is continued in a regulated manner for more than 3 h till the concentrated syrup attained a TSS of 82% and the temperature reaches 120ºC [15].

2.3 Striking Point

The temperature at which thickened cane juice slurry is modified into jaggery is known "Striking Point" The endpoint or striking point was decided manually by dropping a small aliquot of hot syrup into cold water taken in a container where it is solidified. During boiling a small quantity of edible oil is added to prevent frothing. After removal of scum, at the point, temperature plays a major role in the molding of the syrup into different forms of jaggery. The striking point varies from product to product, for solid jaggery making it is at 118ºC, liquid jaggery making is 106-107ºC and for granular jaggery making it is 120-121ºC [1,15,16].

2.4 Cooling and Moulding

After attaining the striking point the concentrated and caramelized hot syrup is brought down from the furnace and is allowed to cool for 15-20 minutes. After cooling the jaggery charge is molded into different forms. The cooling is done by continuous stirring process at regular intervals. The cooled concentrated syrup is transferred into wooden, aluminum (or) steel frames to get different sizes and shapes. About 10-12 kg of jaggery with moisture content of 10-12% (db) is obtained from every 100 kg of sugarcane [1,15,16].

2.5 Process of Liquid Jaggery Making

The intermediate product obtained in the process of making solid or granular jaggery making is liquid jaggery. The liquid jaggery obtained when it reaches to brix of 60-70° with a corresponding boiling temperature (striking temperature) of 105-106ºC, the heating is stopped and removed from the flame. The highly viscous liquid is collected, colled, and filled in bottles with some added preservatives like 0.1% potassium metabisulphite and 0.5% benzoic acid to extend the shelf life [12]. Some liquid jaggery is commercially available at the highest purity and clarity and marked as cane honey (Sukkare). Liquid jaggery is mostly used as confectionery, sweetening agent in sweets and also used as a sauce in idly in North India [10,17].

2.6 Process of Granular Jaggery Making

In the process solid jaggery making process, the semi-solid jaggery concentrate was sheared into small granules with wooden scrapers to form grains instead of molding. The granules or powdered jaggery is also made in granular jaggery making machine or in powder making machine. The initial moisture content of granules is 10-12% (db) which is brought to 1% to 2% by dring in sun, tray, and polyhouse drying. The granular jaggery is sieved and packed in polyethylene bags. Due to its palatability, medicinal value it has better export potential and huge market demand and has shelf life of more than one year. Granular jaggery is used as sugar in our daily dietary allowance and can also be used as sugar in tea and coffee [13,17,18].

2.7 Palmyra-palm Jaggery Making

Fresh Neera was collected by slicing the spath two lines in a day. Neera was collected in lime-treated earthen pot tied to the inflorescence during the previous evening. In overnight neera is ejaculated from the inflorescence, next day morning the pots are removed and the collected neera is filtered through a fine cloth to impure impurities. On average, palm tree secretes about 5-18 liters of juice/day between April and may depending on the ambient temperatures it may also extend till the middle of June [1,19]. The palm juice is susceptible to natural fermentation if kept for a longer time. So it is immediately transferred into a pan for boiling purpose. Before the boiling, clarification (de liming) process was done at 40ºC to reduce the P^H to 7.5 using phosphoric acid or by triple super sulfate solution or by citric acid at the rate of 5 g/50 l of juice was added intermittently during boiling of the juice. The clarified neera was stirred continuously during heating to avoid charring [9,20].

Boiling of neera is done as of sugarcane jaggery making process for about 2 to 2.1/2 hours till syrup attains a TSS of 81% (w/w) and a temperature of 120ºC. The final thick viscous concentrated mass is transferred into wooden cube molds and allowed to cool to room temperature, the viscous mass is solidified during cooling [8].

2.8 Date –Palm Jaggery Making

In the date palm jaggery making process, the sap is tapped throughout November and the end of January. Sometimes it may extend up to the middle of February if the ambient temperature is below 15ºC. After collecting of juice, boiling of juice is done similar to boiling of sugar and palmyra juice boiling, to about 2-3 hours by adding lime and clarificants till it attains TSS of 81% (w/w) with a corresponding striking temperature of 120ºC. A total of 13-14 kg of jaggery is produced from 100 kg of juice from palm juice in comparison of 10 to 12 kg of jaggery from sugarcane juice [1].

Many types of jaggery making pans have been developed in India main variation in design varies in the number of pans and methods of heat supply to the pan [21].

2.9 Two Pan Furnace

Indian Institute of sugarcane research Lucknow (India) has developed a 2 pan furnace system. The juice is boiled/concentrated in a circular flat-bottom main pan and a rectangular gutter pan has been provided over the flue gases passing from preheating of juice to be concentrated in the subsequent lot [22].

Baboo and Anwar [23] improved the thermal efficiency by placing a gutter pan near to the way hot flue gases after the boiling pan. [24] observed that thermal efficiency by increased by 2.6% and bagasse saved by 8% by making changes of forced draft with high natural draft conditions.

2.10 Two Pan Furnace with Fins

The main pan and gutter pan of Indian Institute of Sugarcane Research (IISR) furnace was modified in which fins were provided to the bottom of these pans. For simplicity in fabrication, mild steel flats of 40×50 mm size were welded at 60 mm spacing to the bottom of the main pan and gutter pan. These were welded in lengthwise in the direction of movement of flue gases and thus have been named as parallel fins.

Ganesh [25] found that the use of fins and baffles at the bottom of a single pan improve the thermal efficiency of the plant by 9.44% and energy of 31.34% as compared to traditional plant. Madan (2012) found that the use of fins at the bottom of the boiling pan of a prototype model of the traditional pan can increase the thermal efficiency of the plant from 15.35% to 24.50% and decrease the baggage consumption from 3.83 kg to 2.75 kg.

2.11 Three Pan Jaggery Making Plant

The process of jaggery making in a 3-pan plant is a continuous process without lapse of time process and requires 7-8 skilled manpower. Before boiling all the 3 pans are filled with juice and bagasse is used as a charge, charring is done through a hole below the boiling pan-3 and the temperature in at pan-3 is 1000ºC. The mode of heat transfer for pan -3 is by convection and radiation whereas for pan 2 and 1 is by convection from the hot flue gasses moving towards the chimney under continuous draft. Removing of scum and boiling of juice is a similar process to making of jaggery by single open pan method [26].

After boiling of juice in pan-3 is converted into solid jaggery by evaporation, the 2nd batch of preheated juice of pan -2 is poured into pan boiling pan -3, and preheated of cane juice of boiling pan -1 is poured into pan -2. While fresh cane juice comes into boiling pan-1 through a pipe from the crusher.

It was found that after attaining the striking temperature of 118ºC removal of charge from pan-3 is difficult, which could adversely affect the quality of jaggery. To rectify the problems, a rope and pulley system with gear arrangement was provided to 3- pan furnace system [6].

2.12 Improved 3-Pan Jaggery Making Process

A research study on the improvement of the 3-pan jaggery making plant was done [27] they concentrated mainly on the design of furnace and design of chimney which could improve the combustion of fuel and quality of jaggery making process. For the construction of the furnace in the improved plant, fire bricks (40-50% alum) are used in place of ordinary masonry bricks. The mixing of fuel and combustion air a cast iron grate is provided in the furnace.

On the existing and improved 3 pan furnace, [28] carried out a comparative performance. It was observed that the bagasse consumption of traditional 3 pan jaggery making plants can be improved from 2.24 kg to 1.96 kg jaggery produced using fire bricks with refractory cement, circular cross-section and optimum height of chimney, sliding dampers, and fire grate. [29] fabricated a three pan jaggery manufacturing plant at (IISR) Indian Institute of Sugarcane

Research, Lucknow which resulted in good heat utilization competence of about 34.3%.

2.13 Cooling of Jaggery in Cement Pits

After boiling juice in iron and steel pans at end of striking point stage, it is removed from the pan and is transferred to wooden trays or into cement pits (2-3 in number) for immediate cooling so another batch of juice is ready to transfer into the boiling pan.

3. 4-PAN OR MULTIPLE PAN JAGGERY MAKING

These types of jaggery making process is used for continues jaggery production when required in larger quantities. In 4- pan or multiple pan jaggery making plant, in addition to boiling of juice in a boiling pan and a gutter pan one or two or more pans are placed in series in way of waste flue gases are extracted more heat. The first two pans are used only to preheat the juice by utilizing the thermal energy of hot flue gases. The preheated sugarcane juice is finally transferred to big boiling pans placed at a higher temperature of 1000ºC than of other pans. The direction of the transfer of juice is opposite to the direction of motion of hot flue gases for better utilization of the thermal energy of hot flue gases. The working procedure and design features of 4 pan or multiple pan is similar to 2-3 pan jaggery working plant.

Shiralkar et al. [30] concluded that thermal efficiency consumption in multiple pan jaggery making processes is 46% whereas bagasse consumption is 1.44 k/kg of jaggery produced with 0.13 m^3/s flow rate of air through the furnace. [31] carried a study on the techno-economic feasibility of multiple jaggery making plants and conclude that a 3-pan furnace or multiple pan was more fuel-efficient, economic with continuous production.

4. JAGGERY PRODUCTION THROUGH STEAM FROM BOILER

Steam boiling is a step towards the modernization of jaggery making process. In steam boiling the entire heating is done by boiling of water in the boiler by using bagasse to generate steam. The generated steam is passed through a hosepipe at required pressure and temperature to the double-walled steam kettle for boiling of sugarcane juice to make good quality of jaggery free out of dust and dirt. It saves 17 to 20% of the time and 20-30% better quality. By practicing the traditional jaggery making process 250-500 kg of jaggery is produced depending on place to place. While through steam boiling it is 1 tonne/ day. The main advantage of steam boiling is we can control the flow of heat during making and can produce quality jaggery in lesser time.

5. JAGGERY PRODUCTION THROUGH VACUUM PAN EVAPORATOR

Vacuum evaporation is that the method of inflicting the pressure in a very liquid stuffed instrument to be reduced below the vapor pressure of the liquid, inflicting the liquid to evaporate at a lower temperature than the traditional process. When the process is applied to jaggery the water is evaporated at a lower temperature in a closed container and removed thus good color jaggery can be produced in a short period. The vacuum pan evaporation is the most advanced and automated method in terms of saving time, fuel, and labor. This technology also maintains the quality parameters of jaggery such as color, aroma, texture, and taste which are largely dependent on continuous monitoring and controlling of jaggery preparation. As this technology opens new avenues for jaggery manufactures on large scale production to develop good quality jaggery.

6. OTHER METHODS OF JAGGERY PRODUCTION

Several authors [32,33] proposed a new concept of heat pump based freeze concentration system (FCS) for the concentration of sugarcane juice in jaggery making process. Sugarcane juice flows over a refrigerated surface which performs the function of condenser and evaporator and then transferred to the boiling pan for further concentration. This process improved the concentration of sugarcane juice from 20 to 40 brix resulted in the saving of bagasse consumption of about 1338 kg per day for the production of 1000 kg of jaggery.

Sahasrabudhe et al. [34] developed a mathematical model for analyzing the freeze concentration system of sugarcane juice in jaggery making process and concluded that an optimum freeze concentration system can be designed by estimating the various input parameters. [35] found the optimum process parameters of clarification of sugarcane juice by using the response surface method. [36] fabricated an automatic fuel feeding system for

Table 1. Main finding elements of different jaggery making process

Parameters	**Forms of Jaggery**		
Type of Jaggery	**Solid Jaggery**	**Liquid Jaggery**	**Granular Jaggery**
Form/Shape	Solid form Range(250 g-2 kg) BucketShaped lumps(10-15 kg)	Syrup Form Filled in bottles	Granular Form/Powder form Packed in packet of 1or 2 kg
Moisture Content(db)	10-12%	30-36%	2-3%
Striking Temperature	116-120°C	106-120°C	120-122°C
Composition	Sucrose -65-85% Reducing Sugars-10-15%, Protein 0.25	30-36% water 40-60% sucrose 15-25% Invert Sugar 0.30% Calcium	Sucrose-80-84% ReducingSugars-10.22-12.14% Protein 0.77
Shelf Life	2-3 months	8-9 months	More than 12 months
Reference	[13]	[10,17]	[10,17,18]

the automatic feeding of bagasse of in a crusher to save labor cost and to increase the overall efficiency of the jaggery plant. [37] numerically evaluated and analyzed the process of heat transfer from hot flue gases to juice in an open heat exchanger by using (Computational Fluid Dynamics) CFD simulation tools.

Lakshmi and Mohan [38] observed that the utilization for preheating of sugarcane juice and inlet air improves the performance of jaggery making plants along with saving of bagasse. [39] numerically analyzed the cooling of jaggery by using a heat exchanger for which the velocity and temperature distributions were reported to be by investigational outcomes.

7. CONCLUSION

To make the jaggery industry a profitable business enterprise there is a need to concentrate on improvement of quality making process by practicing advanced methods and methodological conditions starting from extraction, cleaning, clarification, and evaporation process. In addition to this, there is a need for improvement in the design of furnace to decrease the waste of energy generated from flue gases and to improve the overall thermal efficiency. The feature scope of jaggery making process can be achieved by practicing advanced methods. Several researchers, scientists, and enterprisers have designed new methods and tested various methods. These researchers include adopting 2, 3 and 4 pan methods, semi-automated methods like steam boiling methods and advanced methods like vacuum pan evaporator methods and also utilizing fins, baffles, energy boosters, economizer, juice preheater, heat pump based freeze concentration system, etc. The quality of jaggery making can also be improved by making various forms of solid, liquid, and granular jaggery from various sources of input like sugarcane, sugar beet, and palm juices. From the available literature on the up-gradation of jaggery manufacturing technologies, the use of a vacuum pan evaporator was found to be a good approach for the efficient production of jaggery from sugarcane juice.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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