Chapter 2

Literature Review

This chapter is focused on a detailed literature review of jaggery related published work. It is divided into following subtopics

1. Jaggery production status and quality of Jaggery
2. Heat transfer studies of jaggery making process
3. Performance evaluation of jaggery making furnaces
4. Development of fuel-efficient furnace
5. CFD analysis work related to jaggery making furnace

2.1 Jaggery Production Status and Quality of Jaggery

Rao et al. [1] made a detailed study on the production of sugarcane and its products like sugar, khandsari, and jaggery. According to this study, about 24.5% of the cane produced in India is utilized for manufacturing jaggery. As compared to white sugar, jaggery production requires low capital investment and is manufactured at the farmer’s individual unit itself. More than 70% of the jaggery from world production is produced in India.

Sharon et al. [2] conducted studies on energy losses in traditional jaggery processing. They observed, the efficiency of crushing and sugarcane juice concentration is 60% and 14.75% respectively. The low efficiency of heat utilization is due to the use of open pans for the concentration of sugarcane juice and using molds for cooling of jaggery. They suggested that the use of steam jacketed vessels for the concentration of juice, circulation of cold water for cooling the hot jaggery and recirculation of it for steam production and during crushing to make jaggery processing energy efficient.

Kumbhar [3] made a study on jaggery industry in Kolhapur district of Maharashtra. He surveyed 25 random units of Gur manufacturing of the major clusters of Kolhapur district. In his studies, he has reported about Gur profile of Kolhapur district, specialty regarding golden color, chemical free, pure and hygienically produced quality of Kolhapur Gur. Further, he has indicated many health benefits of Kolhapuri gur as it is rich in minerals, it is useful for the strengthening of the
nervous system, relaxation of muscles, relief from fatigue, clarification of blood vessels, antioxidant property helping to scavenge of free radicals from the human body. Rich content of iron in Kolhapur gur helps to prevent anemia, the presence of calcium, phosphorous and zinc offer benefits like purification of blood, prevent rheumatic afflictions and bile disorder. Further, he has made an economic analysis of gur producing units considering cost and return, efficiency ratio, profitability ratio. He reported that gur production is profitable with an efficiency ratio of 1.33 and profitability ratio of 0.338.

Kumar et al. [9] presented a thermal model for greenhouse drying system for jaggery using natural convection and proposed greenhouse dryer for a given mass of jaggery with a thin layer.

Dwivedi et al. [4] and Madan et al. suggested improvement in the jaggery making plant for rural areas. Their suggestions included combustion improvement, controlling air supply for higher recovery of sugarcane juice and use of horizontal roller type sugarcane crusher with multiple passes. This would also reduce the water content of the bagasse so that it can be burnt easily. A significant amount of heat goes as waste through chimney flue gases, the furnace to be modified to accommodate one more preheater pan in addition to main boiling pan for exhaust gas heat recovery. In addition to above, they suggested the use of semi-automatic mechanical feeding system for bagasse to reduce fatigue of fireman, use of baffles along the length of the furnace to regulate flow and retention time of combustion products and use of air blowers or preheated air for better combustion.

Nevkar et al. [11] presented studies on standardization of jaggery powder production process. They reported for fine crystallinity, the striking point temperature of jaggery to be raised by 2°C, i.e. from 118°C to 120°C with drying of jaggery at 45°C temperature for 5 hours in a tray dryer. Further, they suggested 16 no. beaters and 5 mm sieve size for hammer mill operation for increasing efficiency of jaggery powder making process.

Acharya [12] presented a report on modernization of the production process of jaggery. He suggested automation of jaggery plant with the use of controlled crushers with an extraction efficiency of 70% to 80% mechanized juice treatment for clarification which is manual.
Deokate et al. [13] presented an economic analysis of jaggery units. They selected 90 units from Kolhapur, Satara and Pune district. Their studies show jaggery business is profitable with the net return of Rs. 375 to Rs. 498 per quintal for break-even quantity of jaggery production of 374 quintals per batch.

Thangavelu [14] presented a review on sugarcane pans used in jaggery production. He concluded that shape and size of pan decides utilization of heat for heating and evaporation of juice loss by caramelization and charring is comparatively high in round bottom rivetted pans. Galvanized iron pans help in getting jaggery with better color. Further, he has reported in his another publication in 2009 that the quality of jaggery depends upon the content of sucrose in sugarcane juice. The juice with higher sucrose and phosphate and low reducing sugars give good quality jaggery with high sucrose.

Shukla et al. [17] studied causes of deterioration of jaggery and proposed different methods to preserve jaggery. The main constituents which cause deterioration of jaggery are invert sugars and mineral salts which are hygroscopic in nature. This deterioration can be prevented by a coating of edible films produced from edible biopolymers and food-grade additives. Edible film coatings protect jaggery from physical, chemical and microbiological deterioration.

Patil et al. [18] conducted experiments to study the clarification efficiency of synthetic and herbal clarificants for quality jaggery production. They found that use of synthetic clarificants like Bhendi powder or $SN_2[Polymetrololyte]$ 2mg/liter of sugarcane juice enhance scum removal process, improving the color and higher jaggery recovery and also helpful in maintaining the quality of jaggery during storage.

Many researchers Singh et al. [19], Thangavelu [21], Anwar et al. [30] presented studies on production of various chemicals like oxalic acid, citric acid, alcohol, acetic acid, gluconic acid, lactic acid and glycerol by fermentation of jaggery. These products can give more benefit to jaggery manufactures. By the addition of “Anola”, an Indian gooseberry while jaggery making will increase the content of vitamin C. This value-added jaggery becomes a natural source of vitamin C.

Vishal Meshram [2017] presented heat transfer study during jaggery making process. Juice heating process from initial temperature $30^\circ{\text{C}}$ to a maximum striking temperature of $118^\circ{\text{C}}$ was divided into three steps. First stage heating of juice from $30^\circ{\text{C}}$ to $90^\circ{\text{C}}$, considering nucleate boiling phenomena, the second stage boiling of juice in pan from $90^\circ{\text{C}}$ to $102^\circ{\text{C}}$, considering critical boiling phenomena and third stage boiling from $102^\circ{\text{C}}$ to $118^\circ{\text{C}}$ as film boiling. He evaluated heat flux values of $7.8$ KW/m$^2$, $91.45$ KW/m$^2$, and $22.17$ KW/m$^2$ respectively for each stage of heating of juice.

Aldana et al. [33] conducted an experimental analysis of the pool boiling phenomenon of sugarcane juice. Coefficients values of the heat transfer ranging from $4088.6$ W/m$^2$\(^\circ{\text{C}}\) to $12592.8$ w/m$^2$\(^\circ{\text{C}}\) are obtained with heat input ranging from $700$ W to $1300$ W using the method of linear regression and the correlation of Rohsenow. It is found that value of heat transfer coefficient increase proportionally with heat input supplied to sugarcane juice.

Tiwari et al. [34] made a study of heat and mass transfer for natural convection heating of sugarcane juice under open and closed conditions. An indoor experiment was conducted to measure the mass of evaporated water, the temperature of sugarcane juice, the relative humidity above the sugarcane juice surface and the temperatures at the bottom and side of the pot, etc. Regression analysis has been performed by using the experimental data using the Rohsenow correlation for pool boiling and thermal properties correlations for heat transfer. The heat and mass transfer analysis predicted the heat transfer coefficient varies from $50.65$ to $345.20$ W/m$^2$\(^\circ{\text{C}}\) for heat input ranging from $160$ W to $340$ W.

2.3 Performance Evaluation of Jaggery Making Furnaces

Many researchers evaluated the performance of jaggery making furnaces of various types using experimental field data. The work of performance evaluation carried out by various researchers is presented below

Rao et al. [38], collected field data from fourteen jaggery making furnaces to calculate the efficiency of traditional jaggery making furnace. Various data collected
was mass of juice obtained after crushing of sugarcane amount of bagasse obtained, the moisture content of bagasse before and after sundrying the amount and frequency of feeding bagasse into the furnace. The temperature of juice during boiling and the temperature of smoke was also observed. The study revealed that 650 kg of juice and 350 kg of bagasse [50% moisture content] were obtained from one tone of sugarcane crushed. The bagasse was sundried to reduce moisture content from 50% to 20% due to which mass of bagasse obtained after drying was 250 kg. The observations indicated that 650 kg of juice was boiled per batch to get 130 kg of jaggery. In the above process, 500 kg of water was evaporated from juice and 20 kg of scum was removed during boiling. The bagasse required per batch was about 500 kg, so additional bagasse of 250 kg or any other fuel was required for one batch. The time of operation for per batch was about 3.75 to 4.25 hours. Flue gas temperatures at chimney outlet obtained were 350°C to 375°C whereas the temperature of flame during bagasse consumption was about 650°C. They found the thermal efficiency of the furnace to be 14.75% which was low. The bagasse used was 3.85 kg/kg of jaggery produced which is high. They suggested that there is a scope for increasing efficiency of the furnace with the development of a suitable bagasse gasifier to generate producer gas which can be used as fuel for the concentration of sugarcane juice.

Singh et al. [39] carried out the work of performance evaluation of two pan jaggery making furnace. The improved furnace was developed with the addition of gutterpan for preheating of juice. Further, they have used grate made of mild steel flats for the feeding of bagasse to the combustion chamber. Parameters recorded during the trial were mass of sugarcane juice, ambient temperature, initial juice temperature, relative humidity of air, moisture content of bagasse, bagasse consumption rate, mass of jaggery produced. Using the equation for thermal efficiency containing heat utilized for juice concentration and heat supplied by bagasse burnt, the efficiency of two pan furnace was calculated. The overall efficiency of the two pan furnace obtained was 29.3% which was higher than that for single pan furnace which varies from 16% to 19.7%.

Anwar [40] also conducted experiments to calculate the efficiency of two pan jaggery making furnace. He used the concept of fins to increase the effective area of heat transfer from flue gases to the bottom of pans. He conducted experiments using pan without fins and pan with fins. He used nineteen fins on the bottom of main pan
and 10 fins on the bottom of gutter pan which resulted in an increase of heat receiving surface area of 118% and 131% for main pan and gutter pan respectively. He reported heat utilization efficiency of 29.26% for furnace with modified pans which was 9.44% higher than that for furnace with conventional pans which resulted in saving of fuel and energy [31.34%].

Arya et al. [41] conducted experimental trials for evaluating performance for a three pan jaggery making furnace. Two jaggery making plants were fabricated, one with conventional design and other with improved design of furnace, fire gratings, and chimney with exhaust gas damper.

In above studies, it was found that with improved furnace bagasse consumption was reduced by 12% with an increase in 23% production capacity of jaggery. Further CO₂ percentage in exhaust gases was more with improved furnace indicating better combustion of bagasse.

Sardeshpande et al. [42], proposed the procedure for thermal performance evaluation of a four-pan jaggery processing furnace, using mass and energy balance for a jaggery furnace to establish furnace performance and loss stream analysis. The loss stream analysis indicated that the theoretical energy required for jaggery processing is only 29% of the total energy supplied by bagasse consumption Flue gas and wall losses carry out the major loss related with heat. Draft created by the chimney in natural draft furnaces decides the amount of air available for combustion. A measure of the degree of combustion is the oxygen content in the flue gas. Also demonstrated the controlled fuel feeding based on the percentage of oxygen in the flue gases. Fuel consumption reduction from 2.39 kg bagasse/kg jaggery to 1.73 kg bagasse/kg jaggery results when the fuel feeding practice is changed to control feeding rate from traditional. For identification and quantification of losses, this procedure can be used. It also helps in improving thermal energy utilization.

Shiralkar et al. [43], reported comparative studies on the performance of single pan furnace and four pan furnace. In this study two single pan jaggery furnaces were tested for which efficiencies varied from 53% to 76% and 50% to 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 had a taller chimney than the first
contributed to greater air flow due to increased draft. Excess air cause lower combustion temperature, resulting in a decreased rate of heat transfer to the juice.

This study also included tests on one four pan jaggery unit. Calculated efficiencies varied from 42% to 50%. Four pan furnace efficiency was lower because the heat transfer to the main boiling pan is due to both convection and radiation and for the rest of three pans the heat transfer is only by convection. This is due to the rest of the pans are far away from the flame and the view factor is negligible.

Manjare et al. [44] suggested exhaust heat recovery system for preheating of sugarcane juice. Masonry brick tank was constructed around the chimney for preheating of sugarcane juice. The temperature of juice increased by 35°C. They obtained 8.2% increase in efficiency due to use of preheater and bagasse consumption was reduced by 1.2 kg per kg of jaggery production.

Jakkamputi et al. [45], performed analytical calculations by considering mass and energy balance for jaggery furnace. They suggested the use of solar energy for drying of bagasse, preheating of sugarcane juice. They reported that if the sugarcane is preheated close to its boiling temperature, 2560 KJ of heat per kg of jaggery can be saved. Also due to preheating of air and drying of bagasse using solar driers, 0.23 kg of dry bagasse could be saved per kg of jaggery preparation.

2.4 Development of Fuel Efficient Furnace

Lokras [49] has reported development of fuel-efficient biomass burning devices by applying the principles of combustion and heat transfer considering the basic laws of heat transfer as follows:

Conduction: \( Q = K A |T_h - T_c| / L \)

Convection: \( Q = h A |T_h - T_c| \)

Radiation: \( Q = e o A |T_h^4 - T_c^4| / L \)

He suggested that for all the modes of heat transfer, heat transfer rate is directly proportional to the area of heat transfer. The area of the heat transfer can be increased by using any or all of the following options: Use of multiple pans, use of
fins, use of a maximum external area of the pan by dipping it in the flue gases. He developed two pan furnace in which the second pan was provided with fins which resulted in specific fuel consumption of 1.3 kg of bagasse per kg of jaggery against the average specific fuel consumption of 1.9 to 2.0 for conventional two pan unit in Mandya area of Karnataka.

2.5 CFD Analysis Work Related to Jaggery Making Furnaces

Very limited literature is available related to CFD analysis of jaggery making furnaces.

Madrid [46] conducted heat transfer study on open heat exchangers used in jaggery production modules. The main objective of the work was to analyze and evaluate the heat transfer process in each of the pan in five pan jaggery furnace located in the northern highlands of Peru. 3D CFD model was developed for five pan jaggery making furnace which was validated with field data acquired. A commercial CFD software Ansys-CFX tool was used for the simulation of flow and heat transfer characteristics of the jaggery furnace. The geometry of the furnace was divided into three domains for ease of analysis. Further, each domain was subdivided into three computational subdomains each for flue gas duct, pans, and sugarcane juice. The numerical results indicated that in the domain one consisting of 3 pans, the thermal radiation played dominant role compared to convection heat transfer. In domain 2 and three consisting of one pan each convection heat transfer mechanism was dominant. The values obtained for boiling heat transfer coefficients between pans and sugarcane juice were lower than 100000 W/m²K in the three domains which validated the hypothesis of nucleate boiling regime considered in calculations. Results of temperature drop of flue gases across all domains showed a good agreement with field measurements. They recommended to use CFD simulation tools for traditional jaggery furnaces to optimize energy used in a jaggery production module.

Madrid et al. [47] conducted further studies of a jaggery production module using a fire tube heat exchanger. In this study, they used four pan jaggery making furnace consisting of one semi cylindrical, two semispherical and one finned flat pans. The CFD model and simulation of this model was compared with modified
model replacing last finned flat pan by pan with finned fire tube pan. The entire analysis was made as explained in their previous work. They obtained the results showing that for first three pans the heat transfer rate was same as the geometries were unchanged. Only for fourth pan with firetube tube heat exchanger, the heat transfer rate was 92KW which was more than that obtained for finned flat pan [44.9 KW]. The efficiency of the furnace with finned fire tube heat exchanger module obtained was 42.8% compared to 31.4% for furnace with finned flat pan.

Meshram et al. [32], prepared simple 2D CFD model for two pan and four pan jaggery making furnaces using ICEM CFD tool. Using fluent solver, simulation for both the models were done to obtain flue gas flow contours and its temperature variation at the surface of the furnace with pans. Because of the 2D simplified model, they found that flue gases go very fast towards chimney without much heat transfer to the pans.

Jayakumar et al. [48] presented experimental and CFD simulation of heat transfer in helically coiled heat exchangers. Based on experimentation and simulation, they concluded that helical coil heat exchangers give high heat transfer coefficient. Further, they developed a correlation to calculate the inner heat transfer coefficient of the helical coil.

2.6 Summary

Research of jaggery making furnaces can be broadly classified as jaggery status and quality of jaggery, heat transfer studies of jaggery making process, performance evaluating of various types of jaggery furnaces and efforts made to develop fuel-efficient furnace for jaggery making. This chapter makes it easy to understand the gaps in the literature. No research is found related to CFD modeling and simulation of single open pan jaggery furnace. This indicates that with the use of CFD tool, there is a scope for developing thermal efficient furnace for jaggery making. As the single pan jaggery making furnace is simple and commonly used in Maharashtra, the objectives are set based on literature survey and are presented chronologically, starting with the study of heat transfer in various types of jaggery making furnaces.