Chapter 1

Introduction

The sugar industry in India is a well-developed industry and one of the largest after textiles[1]. Sugar is the main product produced from sugarcane juice. Jaggery is also manufactured from sugarcane juice and used widely as a sweetener since ancient times in daily food preparations. It is also used as a sweetening agent in confectionaries and pharmaceutical formulations. Though the Indian sugar industry is well developed, in recent years, it has entangled in complex web problems of high stocks, low prices, poor profitability, high raw material cost, financial crunch and weak international competitive edge. As per the data obtained from various sugar industries, in the year 2017-18 sugar prices touched a low of Rs. 2300-2400 per quintal which are not adequate to cover even the cane price and operating cost of manufacturing sugar. The cost of sugar production includes cane price, harvesting and transportation, process cost and interest if any which comes out to be an average of Rs. 3350 per tonne of sugarcane. Considering yield of sugar per tonne of sugarcane crushed 10%, there is a loss of about Rs.1000 per tonne. The jaggery industry is one of the most important cottage industries in India. Jaggery is prepared by farmers in their own farms as the production of jaggery is very simple, and the capital cost of jaggery plant is also less compared to the sugar industry.

Jaggery production process involves crushing of sugarcane, boiling and concentration of sugarcane juice, molding jaggery into standard shapes, sizes and packaging in suitable packages. In jaggery manufacture, the juice boiling furnaces occupy a prominent place since clarification of the raw juice and its boiling so as to concentrate it to the required concentration is achieved. Many types of jaggery making furnaces have been developed in India [57]. The main variation in designs was due to number and size of pans, size of the combustion chamber, size and geometry of flue gas channel, height of chimney and provision for air supply.
The major drawback with the most of the common furnaces is their excessive bagasse consumption and lower efficiency of heat utilization [35,57]. An efficient furnace should consume minimum bagasse as the bagasse is a good raw material for paper and pulp industry, particle board industry and animal feed industry. So bagasse saving may lead to the way of extra income for jaggery manufacturer. Lower efficiency of furnaces also results in increased processing time of sugarcane juice, so the saving of bagasse and increase in jaggery production can be achieved through the construction of new efficient furnace design or by the modernization of the existing ones.

1.1. Status of Sugarcane Production

1.1.1. World’s Status of Sugarcane Production

Nearly 1900 million tonnes of sugarcane is produced annually in an area of 26.5 million ha in top ten sugarcane production countries in the world. Table 1.1 shows world sugarcane production details. It is seen that Brazil is the biggest producer of sugarcane which at 740 million tonnes grow over 40% of the world’s crop and India is second largest producer with 341 million tonnes of production which contributes to 18% of world’s production [85].

1.1.2. India’s Status of Sugarcane Production

In the year 2015-16 sugarcane was cultivated in an area of about 4.927 m ha which has produced about 348.448 m tonnes of sugarcane [86]. 95% of the sugarcane produced was from Bihar, Haryana, Uttaranchal, Uttar Pradesh, Andhra Pradesh, Karnataka, Maharashtra, and Gujarat, Uttar Pradesh being the maximum producer. Table 1.2 shows statewide area and production of sugarcane in India for the year 2015-16. Out of total sugarcane produced in various states of India, about 50% to 55% is utilized for production of sugar and 30% to 35% is utilized for producing jaggery and khandsari. Table 1.3 indicates statewide utilization of sugarcane in India. The per capita consumption of sweeteners is continuously increasing and projected that through 2020 AD [1], the per capita consumption of sweeteners might boom to 40kg per annum from the level of 34kg per annum in the year 2010. For this reason, the country could want about 50.75 million tonnes of sweetener of which jaggery and khandsari
requirement would be about 23.75 million tonnes. Table 1.4 presents per capita sweetener consumption and requirement which projected values for the year 2020 AD. Thus it can be predicted that the jaggery and khandasari cottage industry would play a dominant role in the processing of sugarcane in a rural area and create employment opportunities to the millions of people in rural part of the country.

**Table 1.1: Sugarcane World Production [86]**

<table>
<thead>
<tr>
<th>Country</th>
<th>Area (million ha)</th>
<th>Sugarcane Production (million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>9.83</td>
<td>739.27</td>
</tr>
<tr>
<td>India</td>
<td>5.06</td>
<td>341.20</td>
</tr>
<tr>
<td>China</td>
<td>1.82</td>
<td>125.54</td>
</tr>
<tr>
<td>Thailand</td>
<td>1.32</td>
<td>100.09</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1.13</td>
<td>63.75</td>
</tr>
<tr>
<td>Mexico</td>
<td>0.78</td>
<td>61.18</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0.45</td>
<td>33.70</td>
</tr>
<tr>
<td>Philippines</td>
<td>0.43</td>
<td>31.87</td>
</tr>
<tr>
<td>Colombia</td>
<td>0.40</td>
<td>34.88</td>
</tr>
<tr>
<td>Argentina</td>
<td>0.37</td>
<td>23.70</td>
</tr>
<tr>
<td>World Total</td>
<td>26.52</td>
<td>1877.10</td>
</tr>
</tbody>
</table>
Table 1.2: Statewide Area and Production for Sugarcane in India (2015-16) [86]

<table>
<thead>
<tr>
<th>State</th>
<th>Cane area (m ha)</th>
<th>Cane production (m tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>0.122</td>
<td>9.353</td>
</tr>
<tr>
<td>Assam</td>
<td>0.029</td>
<td>1.038</td>
</tr>
<tr>
<td>Bihar</td>
<td>0.244</td>
<td>12.649</td>
</tr>
<tr>
<td>Chhattisgarh</td>
<td>0.036</td>
<td>0.068</td>
</tr>
<tr>
<td>Gujarat</td>
<td>0.157</td>
<td>11.12</td>
</tr>
<tr>
<td>Haryana</td>
<td>0.093</td>
<td>6.692</td>
</tr>
<tr>
<td>Jharkhand</td>
<td>0.01</td>
<td>1.709</td>
</tr>
<tr>
<td>Karnataka</td>
<td>0.45</td>
<td>37.834</td>
</tr>
<tr>
<td>Kerala</td>
<td>0.001</td>
<td>0.138</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>0.103</td>
<td>5.281</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>0.987</td>
<td>73.68</td>
</tr>
<tr>
<td>Orissa</td>
<td>0.009</td>
<td>0.577</td>
</tr>
<tr>
<td>Pondicherry</td>
<td>0.09</td>
<td>6.607</td>
</tr>
<tr>
<td>Punjab</td>
<td>0.006</td>
<td>0.531</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>0.252</td>
<td>25.494</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>0.035</td>
<td>2.405</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>2.169</td>
<td>145.385</td>
</tr>
<tr>
<td>Uttaranchal</td>
<td>0.097</td>
<td>5.886</td>
</tr>
<tr>
<td>West Bengal</td>
<td>0.017</td>
<td>2.075</td>
</tr>
<tr>
<td>Others</td>
<td>0.02</td>
<td>0.926</td>
</tr>
<tr>
<td>Total</td>
<td>4.927</td>
<td>348.448</td>
</tr>
</tbody>
</table>
### Table 1.3: State-wide Utilization of Sugarcane in India [76]

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>59.6</td>
<td>32.8</td>
<td>69.5</td>
<td>22.8</td>
<td>63.3</td>
<td>29.0</td>
<td>55.8</td>
<td>36.6</td>
<td>57.9</td>
<td>34.5</td>
</tr>
<tr>
<td>Haryana</td>
<td>54.7</td>
<td>32.8</td>
<td>66.8</td>
<td>20.7</td>
<td>67.4</td>
<td>20.1</td>
<td>73.2</td>
<td>14.4</td>
<td>67.6</td>
<td>19.9</td>
</tr>
<tr>
<td>Karnataka</td>
<td>32.2</td>
<td>58.5</td>
<td>37.6</td>
<td>39.7</td>
<td>39.3</td>
<td>27.6</td>
<td>34.8</td>
<td>26.4</td>
<td>43.8</td>
<td>24.9</td>
</tr>
<tr>
<td>Punjab</td>
<td>50.9</td>
<td>36.6</td>
<td>59.8</td>
<td>27.7</td>
<td>68.8</td>
<td>19.2</td>
<td>65.8</td>
<td>21.7</td>
<td>67.9</td>
<td>19.6</td>
</tr>
<tr>
<td>TN</td>
<td>48.0</td>
<td>41.9</td>
<td>57.4</td>
<td>32.5</td>
<td>54.5</td>
<td>35.4</td>
<td>55.7</td>
<td>34.2</td>
<td>58.7</td>
<td>31.2</td>
</tr>
<tr>
<td>UP</td>
<td>31.6</td>
<td>54.6</td>
<td>35.4</td>
<td>50.8</td>
<td>42.3</td>
<td>43.5</td>
<td>43.2</td>
<td>43.0</td>
<td>46.8</td>
<td>39.4</td>
</tr>
</tbody>
</table>

### Table 1.4: Projections of Sweetener Requirement in India [1]

<table>
<thead>
<tr>
<th>Year</th>
<th>Expected population million</th>
<th>Per capita expected Consumption, Kg/annum</th>
<th>Sweetener requirement, million tonnes including, export</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sugar</td>
<td>Jaggery &amp; Khand-sari</td>
</tr>
<tr>
<td>1998-99*</td>
<td>950</td>
<td>14.9</td>
<td>10.4</td>
</tr>
<tr>
<td>2010</td>
<td>1100</td>
<td>19.0</td>
<td>15.00</td>
</tr>
<tr>
<td>2020</td>
<td>1250</td>
<td>21.6</td>
<td>19.00</td>
</tr>
</tbody>
</table>

*Actual: projected data calculated by expected human population and per capita consumption of sugar.
1.2 Status of Jaggery export

Jaggery is produced in 25 countries with a world annual production of 11.05 million tonnes (FAOSTAT 2003). The major production is concentrated in Asia and South America, the major producer being India with 6.8 million tonnes per annum. Since the jaggery has many health benefits, the jaggery use trend is increasing at international level. Status of jaggery export from India is presented in figure 1.1 and 1.2. Jaggery is exported to Nepal, Myanmar, Benin, United Arab Emirates and Nigeria. The export of jaggery is increasing since 2012-13 [76], and in the year 2016-17 the jaggery worth of 219 USD Mill was exported to various countries. India’s export growth trend in last five years is presented in figure 1.3 which shows that the demand for jaggery from India is almost constant.

![Image of a pie chart showing the export distribution of jaggery from India to different countries. The chart indicates the percentage contribution of each country to the total export. Nepal contributes 6%, Myanmar 9%, Benin 15%, United Arab Emirates 15%, and Nigeria 19%.]

Figure 1.1: India’s Jaggery Export Status Year 2016-17 [76]
Figure 1.2: India’s Jaggery Export Trend in Last Five Years [76]

Figure 1.3: India’s Jaggery Export Growth in Last Five Years [76]
1.3 Overview of Conventional Jaggery Making Process

This section deals with the stages in the entire process of jaggery production. Figure 1.4 shows flow diagram for jaggery making process. It begins from the stage of harvesting of sugarcane and followed by several stages till the time of getting the finished product. There are four stages involved in the production of jaggery viz. harvesting of sugarcane, extraction of juice, clarification of juice, and solidification of juice into jaggery. The quality of jaggery and its recovery vary widely from one place to another. There are very few places where jaggery is known for its better quality, higher recovery and good storability. The cultivation practices, the variety of cane used, the juice clarification technique equipment's and processes contribute to the quality and recovery aspects.

It is important to note the fact that even though Jaggery making starts with the extraction of cane juice, it is necessary to cut and to bring the cane at the place of jaggery making unit. Therefore, sugarcane cutting and transportation are the two basic steps before cane crushing. The other steps in jaggery making are as follows. Figure 1.4 shows Process flow diagram for jaggery plant.

1.3.1 Extraction of Juice From Sugarcane

Extraction of juice from sugarcane is done with the help of a cane crusher. Presently improved designs of cane crushers are used which are driven by an oil engine or an electric motors. About 1 tonne of juice is obtained after crushing of 1.5 tonnes of sugarcane.

1.3.2 Boiling of Juice

Once the juice is extracted from the sugarcane, it is taken for boiling. In India, open pan method is used for jaggery making. Hence juice is boiled in open pans. These pans are made up of mild steel sheets. For the better color of jaggery galvanized iron pans are also used. For the single pan jaggery furnace, the pan is placed over pit type of furnace made from masonry bricks cemented with earth clay. For multi-pan furnaces the second, third and fourth pan are placed in line along the length of flue gas duct depending upon a number of pans used in the plant. Bagasse acts as the main source of fuel for these furnaces.
1.3.3 Purification of Juice

The juice which is heated and boiled releases out many impurities that needs to be removed. Thus, purification of juice is the main deciding factor for color, texture, test, and durability of jaggery. For purification of juice, the most common purifiers used are lime, sucrose, sodium carbonate, sodium bicarbonate, suiji, superphosphate, alum, sodium hydrosulphite, etc. Generally, Okra powder (Indian name Bhendi) is used in conjunction with other purifiers when the juice is boiled at low temperature. It facilitates to bring the impurities scum to the surface of the pan. This scum is skimmed out, and consequently the juice is purified.

1.3.4 Concentration of Juice

The next step after purification of juice is a concentration of juice which is boiled at the striking point of temperature that normally ranges between 118°C-120°C [43]. The proper concentration of juice is judged by applying one of the following methods:

- A small mass of concentrated juice is taken from the pan using a wooden stirrer and is put into cold water. The mass is then rolled into a ball. If the ball is hard enough to produce a metallic sound when thrown against the side of the pan, it is considered as completion of the process of boiling the juice. At the striking point, if the boiling mass is stirred, it does not stick to the pan.

- At the striking point, the sticking mass forms a long silky thread which does not fall in drops.

Thus, by applying one of the above methods to find the striking point or an appropriate point of concentration of juice, the pan is then removed immediately from the furnace and is stirred for some time. The boiled liquid jaggery is transferred into a cooling pan.

As the temperature falls, the jaggery begins to crystallize. By stirring the juice slowly and intermittently to avoid the loss of granular structure, the semi-solid mass is then put into moulds. When the jaggery solidifies it is removed by inverting the moulds. These lumps or molds are made to take the shape of a bucket of different
weights. These buckets are of 10 kg, 5 kg or 1 kg etc. These buckets vary in size, but have the uniform shape having different weights of jaggery lumps.

![Process Flow Diagram for Jaggery Plant](image)

**Figure 1.4: Process Flow Diagram for Jaggery Plant**

### 1.4 Jaggery Making Protocol

In order to obtain jaggery of good quality, the standard process of jaggery making is developed by Regional sugarcane and jaggery research station, Kolhapur. Figure 1.5 presents jaggery making protocol [84].

After crushing of sugarcane, juice obtained is taken to settling tank through metal wire grid filter. Before processing to boiling sugarcane juice pH value of 5 to 5.2 and Brix value 20 to 21 is ensured then it is transferred to boiling pan for the first phase boiling. In first phase boiling up to 90°C, Ockra plant mucilage or Bhendi stalk powder is used with the combination of calcium oxide to remove black scum and change of juice color from blackish to yellowish. During this process pH value of Juice increases to 6.2 to 6.4. In next phase of juice boiling up to 105°C phosphoric acid is added to reduce pH value
of juice to 5.5 and remove golden scum. After this phase cooking oil is added to the juice and juice is concentrated to the striking point temperature of 118°C and Brix value of 90°. Then the juice is taken to the cooling basin for solidification.

1.5 Types of Jaggery

In the market, special types of jaggery are available, and to manufacture them particular types of clarificants are required. Manufacturing of such type of jaggery has been suggested for presenting the produce to the consumers in different forms and varieties.

1.5.1 Solid Jaggery

Most of the jaggery produced in India is in solid form. The solid jaggery is obtained by concentrating of sugarcane juice up to a striking temperature of 118°C which corresponds to 90° brix. This type of jaggery is commonly used in daily food preparations.

1.5.2 Liquid jaggery

Liquid jaggery is a mid-product obtained during jaggery making process. Its striking point temperature lies between 105°C - 108°C depending upon cane variety.
and agro-climatic zones. The liquid jaggery also commonly known as kakavi, free from impurity is filled in sterilized bottles. Benzoic acid and citric acid are added as preservatives. It is utilized as a sweetening agent in food and drinks in Maharashtra, Gujrat, Kerala, Andhra Pradesh and Tamil Nadu.

1.5.3 Powder Jaggery or Granular Jaggery

For making crystalline granular or powder jaggery, juice pH is adjusted to 6.0 to 6.2 by adding lime solution and juice is boiled and clarified simultaneously using deola mucilage as clarificant. The striking point temperature for powder jaggery ranges from 120-122°C. The hot mass is cooled in the cooling pan with puddling and left without stirring for a few minutes for crystal and slurry formation. At this solidifying stage, the mass is made in granular form by shearing action between the wooden scrapers and palm, dried to the moisture level of 1-2% and sieved through 3mm size sieve to get uniform sized granules.

1.6 Medicinal Properties of Jaggery

Jaggery from old time has been reported to have multiple health benefits. Jaggery, when used daily, may increase human lifespan. In jaggery consuming areas, less incidence of diabetes is reported compared to sugar consuming areas. Historical medical scriptures, Sushruta Sanhita (Chapter 45, sloka 146), dating back to 2500 years states usefulness of Jaggery in the purification of blood, prevents rheumatic afflications, issues of bile, and it has high nutritive properties. Jaggery supplements the requirements of calcium and iron in women and children, preventing anemia and thus enlarging vitality and helping in digestion. Elements in Jaggery such as Magnesium give strength to the nervous system. Potassium maintains acid balance in the cells also combats acids and acetones. The preventive action of jaggery on smoke-induced lung lesions and the presence of micronutrients in jaggery have antitoxic, and an anticarcinogenic property suggests the potential of jaggery as a protective agent for workers in the industry in smoky environments. Also, it has potential antioxidant activity owing to the presence of polyphenolic compounds in cane juice.
1.7 Objectives of this research

From the literature review, it was noted that very few researchers have focused on heat transfer study of jaggery plants. Very few research was found on CFD analysis of single open pan jaggery making a furnace. Also from the field visits made at 30 jaggery plants in Kolhapur district which is famous for quality jaggery production, it was found that there is no standardization of pan size, furnace shape, and height of the chimney. This has inspired to undertake the work as a research problem, and the objectives of the work are as given below.

1. To study the various types of furnaces used in jaggery making plants.
2. To study the combustion process in jaggery furnace using bagasse as fuel.
3. To carry out CFD analysis of single open pan jaggery making furnace and validate the numerical results with experimental field data.
4. To develop CFD model for typical standard size furnace constructed with fire bricks along with fins at the bottom of pan and to carry out CFD simulation of this geometry.
5. To design and develop innovative pan with a spiral coil heat exchanger.
6. To carry out CFD modeling and simulation of single pan jaggery making furnace with the innovative pan.

1.8 Outline of the Thesis

The thesis is organized regarding the objectives accomplished. Chapter one gives a brief idea about the status of sugarcane production worldwide and in the country. It also provides detailed information on production, consumption, and demand of jaggery with its health benefits. This chapter concludes with the objective of the study. Chapter two provides an extensive literature review of the relevant areas required for the current research. In chapter three, various types of jaggery making furnaces are explained considering heat transfer studies. Chapter four covers field data collected for various jaggery making furnaces and experiments performed for various geometries of jaggery making furnace and pan. Chapter five focused on CFD modeling and simulation of existing jaggery making furnace and validation of the numerical results of CFD analysis with field data acquired. Chapter six covers the detailed modeling and CFD simulation of jaggery making furnaces with two modified pan designs, including a comparison of numerical results obtained for cases
mentioned above. Chapter seven includes conclusions and recommendations for the future work.