The Review on Jaggery Making Process and Preparing CFD Model to Analyse Heat Transfer.

Vishal Abhiman Meshram[1], Deepti A. Deshmukh

Assistant Professor, Mechanical Dept., ICEM, Pune[1]
vishalam85@gmail.com[1]

Abstract— Jaggery Processing Plant is one of the most ancient and important rural-based cottage industries in the India. It provides jobs to the unemployed rural people in their vicinity with minimum capital investment and get manufactured at the Farmer's individual units itself. A Jaggery processing plant mainly requires mechanical and thermal energy for processing. The production process of Jaggery involves crushing of cane, boiling & concentration of juice, moulding into the standard shapes & sizes and packaging in suitable packages. The boiling & concentration of juice is performed in Pan using different kind of furnaces. Many types of Jaggery making furnaces have been developed in India. Main variation in designs was due to number and size of pans, size of combustion chamber, size and geometry of flue gas channel, height of chimney, provision for air supply, etc. In this progress report, the review has taken on Jaggery making process industries to study the geometrical and constructional difference. Due to this difference Jaggery plants are classified into Single Boiling Pan, Double or Two Boiling Pan and Multi-Pan. By comparing all these types of plants for Jaggery making process which leads to good quality Jaggery at the end of production, a common protocol has been made to monitor process requirements. Also, some experimental trial has been taken on single pan, two pan & four pan Jaggery plant to study existing energy efficiency performance. During this survey, Process has been monitored to get required Jaggery quality by noting the consumption of bagasse, Temperature of flue gas at Combustion place, Temperature at Chimney exhaust with normal supply air and chimney draft, and Temperature of Jaggery at each stages of process.

In this paper, CFD model of double pan and four pan Jaggery furnace has been analyses to observe flue gas temperature from combustion place to chimney

Index Terms—Heat Transfer, CFD, Jaggery plant Furnace, Steps of Jaggery production.

I. INTRODUCTION

Jaggery industry has been one of the most ancient and important rural-based cottage industries in the India. It provides jobs to the unemployed rural people in their vicinity with minimum capital investment and is manufactured at the Farmer's individual units itself. It has higher medicinal and nutritional values and easily available to the rural people. Sugarcane is grown in an area of about 4 million hectares of land in India with an average yield of 66 tonnes per hectare. With this about 273 million tonnes of sugarcane is produced annually. This sugarcane is processed for making sweeteners like Sugar, Jaggery or Khandsari. Out of total sugarcane produced, 66.7% is used for making sugar and 20.7% is utilized by Jaggery and Khandsari under the decentralized sector. Remaining is used for seed, feed, chewing or raw juice drinking purposes in summer days [1].

The production process of Jaggery involves crushing of cane, boiling & concentration of juice, moulding into the standard shapes & sizes and packaging in suitable packages. The boiling & concentration of juice is performed in Pan using different kind of furnaces. This research focus on heat transfer involved in Jaggery making process and optimized it to maintain quality Jaggery with recovery of heat loss. Meanwhile it should reduce bagasse consumption which required for combustion heat generation and optimized production time in different types of jaggery plants. The heat balancing of Jaggery making furnace has shown in fig. 1.

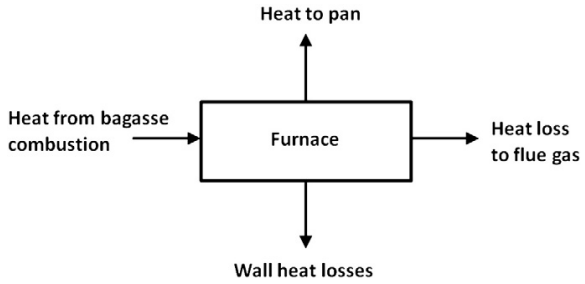

Fig. 1. - Heat balance for a Jaggery making furnace [6].

Apart from furnace heat transfer, the heat goes to Jaggery pan will be used for Process of Jaggery making. This utilization will be done in different size and number of pan of the Jaggery plant.

In other hand, Sugar cane juice collected in selting tank is transferred to boiling pan for boiling and concentration. The process of boiling and concentration is end up at around temperature 118°C of juice reached by furnace heat with the help of bagasse combustion. After the boiling and concentration process, concentrated juice transfer to cooling pan for cooling and solidification. Generally, Jaggery was during solidification process. And it stored in warehouses for trading.

From the research paper of G. N. Tiwari et al. [3], the heat transfer relation and thermal property get to known. He has conducted an indoor experiment to measure, the mass of evaporated water, the temperature of the sugarcane juice, the relative humidity above the sugarcane juice surface and the temperatures at the bottom and side of the pot etc. also Anil Kumar and G. N. Tiwari [16] published, the experimental work on effect of shape and size by evaluate the convective mass transfer coefficient during drying of Jaggery in a controlled environment for natural as well as forced convection. Similarly, Mahesh Kumar [17], explain his work on the natural convective behavior during internal heating of sugarcane juice in a stainless-steel pot for jaggery making. Various indoor experiments are conducted for internal heating of sugarcane juice in stainless steel pot by varying heat inputs from 200 to 360 watts. The experimental data are used to determine the values of constants in the Nusselt number expression by simple linear regression method and then the values of the convective heat transfer coefficients are determined. Zailer Astolfi-Filho at el [18], published a paper on Thermo-Physical Properties of Industrial Sugar Cane Juices for the Production of Bioethanol. To design equipment for biofuel production and an optimizing process for heating, settling, and filtration of industrial sugar cane juices, these thermo-physical properties must be known for sugar cane juice heat transfer analysis.

II. SURVEY AND REVIEW ON JAGGERY PLANT

According to survey, there are different types of Jaggery making plants in existence in India. These differences are in mainly because of size of pan, and number of pans used for Jaggery making process. Based on this Jaggery making plants are classified into three categories namely, Single pan (Main Boiling Pan Only), Double Pan (Use Main pan & Gutter Pan for pre-heating of sugarcane Juice), and Multi- Pan (use three or four pans for each stages of boiling of Sugarcane Juice during Jaggery making). In all these plants according to the production capacity of plant, size of pan gets decided. Now a days, most of the plants are standardized by production capacity because of several reasons. Therefore, main classification that being taken in this study is based on number of pans used for boiling of sugarcane Juice.

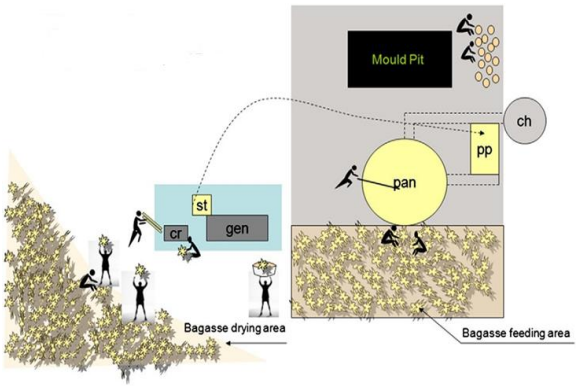

Fig. 2. - Layout of a typical Jaggery unit in Kolhapur district. (gen: generator; ch: chimney; st: intermediate storage-1; pp: intermediate storage; cr: crusher) [6]

As shown in fig. 2, Single Pan Jaggery plant's common layout has been installed and operated in Kolhapur, it has production capacity of about 200 kg Jaggery with 1000 kg sugarcane crushing per batch. According to number of batches daily production get vary. Each batch of production run one after another which has minimum time span of 120 minutes and maximum span of 180 minutes. In this plant, one crusher unit to extract juice run with the help of prime mover, one Juice filtration & process storage system, one boiling pan and one cooling & moulding pit has been used for Jaggery making process. For heat generation, fire bricks furnace has been made to combust Sugarcane bagasse used after drying in sunlight. Furnace air inlet and chimney made such a way that it has natural draft air flow for combustion.

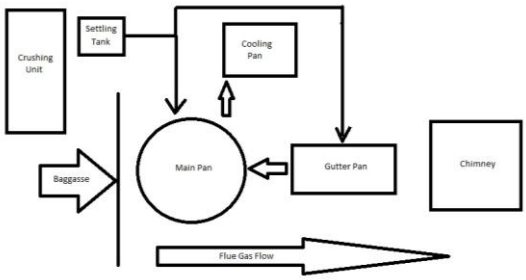

Fig. 3. - Two Pan Jaggery Plant layout.

Similarly, Double pan Jaggery plant has been installed and operated. Only the differences in number of pan and heat recovery techniques used in this plant by placing Gutter pan in a flue gas flow passage before chimney and after main furnace. Gutter pan, which is secondary pan in jaggery making process used in this plant, hence it known as double pan Jaggery plant. Fig 3, shows the layout of Double pan Jaggery plant used in practice. Main pan of this plant was same as single pan in design, but gutter pan has rectangular shape. As gutter pan has been designed to recover heat from flue gas flowing through passage on which it mount to get convective heat transfer to Sugarcane juice. After first boiling phase and black scum removed juice will pass to Main pan for further boiling by plastic or stainless-steel pipe.

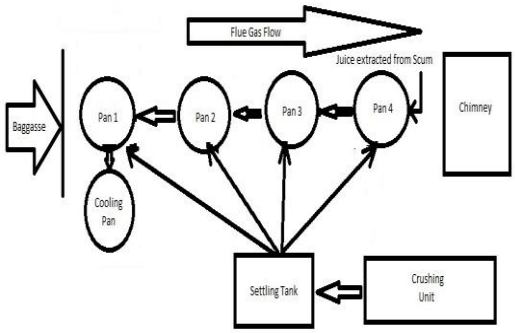

Fig. 4. - Four Pan Jaggery Plant layout.

And Multi-pan Jaggery plant has three or four pan in-line on Jaggery furnace. Typical four pan Jaggery making plant has been shown in fig. 4. All four pans used for boiling phases of Jaggery making are circular in cross section having tori-spherical shape at bottom. Complete furnace has been made up of concrete material, all pans has mounted on top of furnace combustion and flue gas flow passage. One end of this furnace used to feed bagasse and remove ash below grade and other used to remove flue gases to the chimney. Comparative large capacity pan used for final boiling phase of 118 °C above position of combustion. And in descending capacities pan has used afterword on flue gas passage. Most commonly material used for this kind of plants are galvanising sheet metal of 36 gauge.

A. Existing Operational Survey

According to Survey of Jaggery making Industries, there are three main segments namely, Selection of Sugarcane for Jaggery Process, Sugarcane crushing for Juice extraction & Bagasse preparation, and Boiling & concentration of Juice to make Jaggery with the help of Bagasse combustion in furnace. Each segment play important role to make final quality of Jaggery.

a) Selection of Suagar Cane for Jaggery making

The sugarcane of type Co 92005, co 8014(mahalaxmi), CoC 671(vasant) will mature for juice early whereas Co 86032(Nira) and Co 94012(Phule-savitri) will take time of 11 months or more. Avoid giving water in sugarcane farm 15 days before when sugarcane will plan to use for Jaggery making. To test sugarcane is mature for jaggery making process or not, use Brix-meter. If Brix value is more than 21 on Brix scale then sugarcane is ready for Jaggery making otherwise not. Brix test should be done in morning.

b) Juice extraction and Bagasse preparation

Sugarcane should use for Jaggery making process within 6 to 12 hours after taking it from Farm for good quality Jaggery. Otherwise Sugarcane start degrading and losing its nutrition value. Sugarcane should crush with the help of sugarcane crusher about 65 to 70 % to avoid contamination of small size cane particles in juice and getting good quality bagasse for combustion in Jaggery furnace. Avoid Iron contact to juice, it spoil juice by reacting with phenolic particles presence in juice. Use Stainless steel or food grade plastic to handle Juice for Jaggery Processing. Filter Juice with the help of Nylon mesh filter. Before collecting it to juice container.

c) Boiling and Concentration by Bagasse combustion

Sugarcane juice has been transfer to Boiling pan made up of Galvanizing or stainless steel sheet of difference shape and size. For heat recovery from flue gas generated by combustion of bagasse, single pan boiling method has been modified into two pan & multi-pan type. Also there were different techniques being used in pan making like sheet riveting or bottom side fins to enhance heat transfer to pan. For making solid Jaggery, juice has been boiled up to 118°C and then cooled in cooling pan till 75°C. Cooling pan has made up of concrete at the most of the sites used to hold heat during moldings of Jaggery in different shapes.

After doing all above study, focus of project was on boiling and concentration process of Jaggery making. During last progress work, detail study of temperatures with respect to time has been carried for the boiling and concentration process of Jaggery making and furnace temperature at combustion & chimney exit to understand heat balance in existing plants. The work carried out on Single pan, two pan & four pan Jaggery plants at Pune.

In Jaggery making process, Sugarcane juice has been boiled to evaporate water contain from it and concentrated Juice has cooled down for molding it in solid shapes. Combustion heat of Bagasse & Flue gas Temperature utilization play important role in each steps of boiling & Concentration of Jaggery making process. So, Current work focus on estimation of existing Temperature generated due to combustion of bagasse and Flue gas temperature in Jaggery plant at exit from Chimney. Based on this study Improvement of Heat Utilization in Process of Jaggery making should be done.

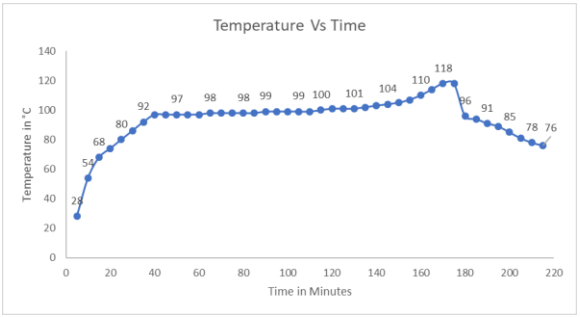

Fig. 5 – Normal Jaggery making time with processing temperature for a single batch of production

The daily production of any jaggery making plant is about 1000 kg of solid Jaggery. But as there are various types of jaggery plants such as, Single pan, double pan and multi-pan Jaggery plant having difference in their pan sizes for boiling of sugarcane juice, which ultimately results into time required to complete jaggery making process and amount of bagasse consumed during jaggery making process. Single pan consistently take approximate same time for each batch and same amount of bagasse being consumed. Whereas in double pan jaggery making plant during first batch take time similar to Single pan jaggery plant but second batch onward double pan jaggery plant utilized flue gas heat in gutter pan to save bagasse consumption for jaggery making and also compact production time cycle of jaggery making. Major focus of study was to observe Temperature generated by bagasse combustion, Temperature gain by Sugarcane Juice in Boiling pan & Flue gas temperature at chimney exit. In next section of report the details of survey has explained.

B. Bagasse consumptions in existing Jaggery Processing

The observations of Single, Double and Four Pan Jaggery plants has compared based on time required to produce Jaggery in various batches in a day. Fig. 6 represent Bagasse combustion temperature measured in °C of furnace with respect to first production batch time in minutes of the day of Single pan, double pan and four pan Jaggery plant. It shows all plants was taken maximum temperature rise at about 1250 °C with same time pattern. Four pan Jaggery pan complete batch in earlier time compare to single and double pan Jaggery plant because of less quantity of Juice boiled in small size pan compared to others.

For same case of all above plants bagasse consumption for each 10 minute combustion with respect to time of Jaggery production batch has represented in Fig. 7. Differences has been noted in all plants as per progress in process of Jaggery making. Four pan Jaggery plant consumed 239 kg of bagasse, Double pan consumed 296 kg of bagasse and single pan consumed 343 kg of bagasse for total boiling process of jaggery making. Consumption of bagasse depend on size of combustion furnace and rate of air flow for bagasse combustion.

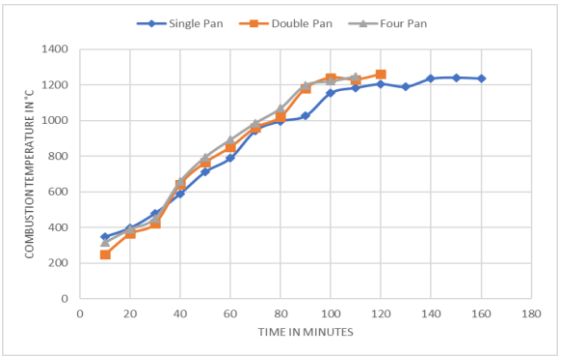

Fig. 6 – Combustion temperature Vs time required to complete 1st batch of boiling

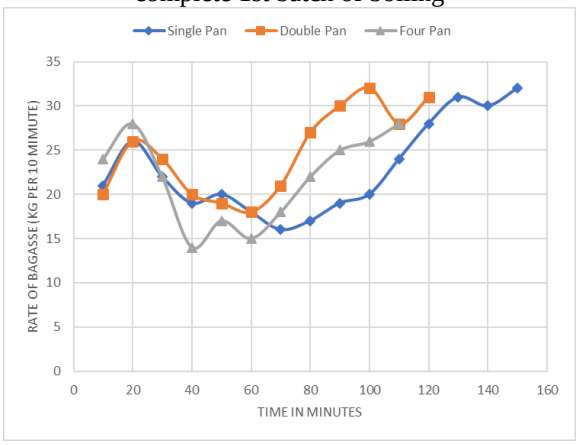

Fig. 7 – Rate of bagasse feeding Vs Time of 1st batch boiling.

Second Jaggery making batch onwards, Double and Four pan Jaggery plants combustion time reduced significantly compare to single pan Jaggery plant because of heat recovery technique.

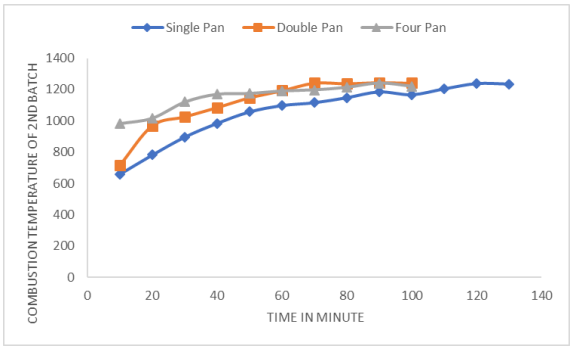

Fig. 8 – Combustion temperature Vs time required to complete 2nd batch of boiling.

In second batch, furnace temperature rises quickly because of previous batch combustion heat available in furnace. In Fig. 8, temperature of four pan Jaggery plant was Reduce very less compare to single and double pan Jaggery plant. Because of continuous production nature and furnace permanently coved by boiling pans, hence it restores more heat of combustion. Whereas, single and double pan plant's boiling pan was removed at the of batch to pore concentrated juice to cooling pan meanwhile furnace has been open to the atmosphere and loss more heat of combustion. That was the reason, represent in fig. 8, starting temperature of boiling in single and double pan Jaggery making process was low compare to four pan Jaggery pan.

For same case of 2nd batch of jaggery making, bagasse feeding rate has been observed. Fig. 9 represent, bagasse feeding rate for each 10 minutes with respect to time of boiling and concentration of juice. Single pan consumed 269 kg of total bagasse, double pan consumed 206 kg total bagasse and four pan consumed 172 kg total bagasse for combustion to complete boiling and concentration phase

of 2nd batch Jaggery making.

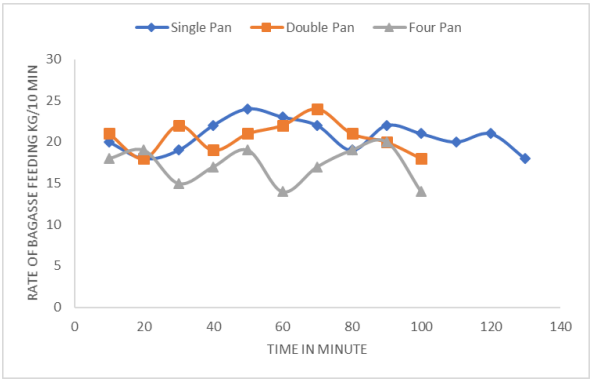

Fig. 9 – Rate of Bagasse feeding Vs Time of 2nd batch boiling.

III. JAGGERY MAKING PROTOCOL

There are mainly three types of Jaggery Processing Plants. Namely, Single Pan (Boling Pan Only), Two Pan (Gutter Pan & Main Boiling Pan) and Multi-Pan (Three & Four boiling Pan). In all these plants, Sugarcane juice is boiled and concentrated. Afterword, it cools down and mould in solid shape called Jaggery.

Jaggery making process mainly required mechanical & thermal energy at a plant. First mechanical energy used to crush Sugarcane which come from sugarcane farm to the site of Jaggery Plant. Now a day's electrical motor drive used, which run on regular electrical supply or Diesel power generator. Some crusher is use diesel engine to drive it directly. After crushing Sugarcane Juice has taken in settling tank through metal wire grid filter. Before processing to boiling, sugarcane juice should insure for pH value and Brix value (expected pH = 5 to 5.2 and Brix = more than 21), then it transfers to boiling pan for first phase boiling. In first boiling phase (up to 90°C), Ockra Plant Mucilage or (Bhendi stalk) powder used with the combination of Calcium oxide to remove black scum and change of juice colour from blackish to yellowish. During this pH value of juice get increase. In next phase of juice boiling up to 105 °C, phosphoric acid is added to reduce pH value of juice and remove golden scum. After this phase, juice has been boiled for third phase above 105 °C and cooking oil (hydrous oil) get added into juice. At around 118 °C juice get concentrated, to test its concentration do ball test or observe bubble cream formation on upper layer of juice. At this step, Juice is taken to cooling pan for solidification. Then it stored for marketing. This protocol has been followed by all kind of Jaggery Plant. Above protocol was monitored for Single pan, two pan & four pan type of Jaggery plants, experimental trial has been taken for a complete day production cycle.

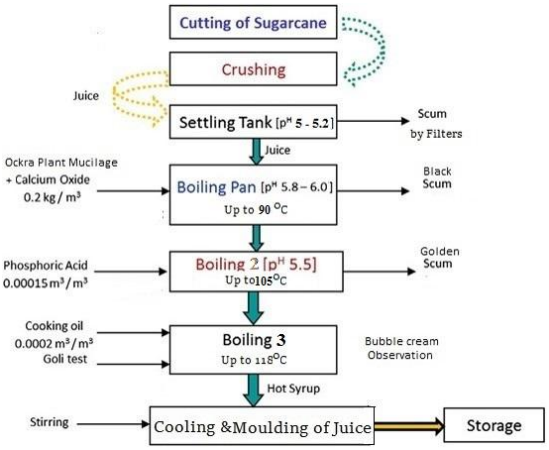

Fig. 10 - Jaggery Making Protocol used for various plants.

As per protocol of Jaggery making prepared as shown in fig. 10. Boiling process start after crushing of Sugarcane. For the boiling process 700 kg of Juice come out of 1000 kg Sugarcane, remaining treated as bagasse which will used in furnace for combustion after drying. 700 kg of juice goes through boiling and concentration process and gives 180 kg of solid Jaggery after cooling hot syrup of Jaggery.

Before utilizing combustion energy to increase overall performance, this research work helped to calculate quantities of heat transfer involved during Jaggery making process. These values are mentioned in following points.

a) Total Heat generate in furnace by combustion is 6174 MJ for the calorific value of bagasse 18000 kJ/kg for the Boiling and concentration process in 2 hours and 20minute time.

b) Total Heat Utilized for Boiling of Jaggery is 1368.28 MJ for 2 hours and 20minute time. This heat helps to evaporates water from Sugarcane Juice.

c) During cooling process of Jaggery, heat loss from hot syrup is 5443.64 W/m2 which depend on surface area of syrup exposed to air.

d) During molding syrup in solid shape, Jaggery cooling process loss heat of 17836.27 W/m2 and moistures.

e) At last mold are kept in free space, where it cools down to room temperature with loss of 1862.39 W/m2 heat flux.

As in this case of Single pan Jaggery plant, most of heat of combustion lost through chimney with flue gas. Which will be recovered by Double pan & Four Pan Jaggery plant by having preheating pan aligned with main boiling pan. Double pan & Four Pan helps in recovering combustion heat generate in Furnace. To observe this phenomenon CFD Model has been prepared which has been discussed in next chapter.

IV. CFD MODELLING FOR FURNACE

As per design survey of various type of Jaggery Making plant, the furnace was made up such a way that bagasse has been fired on grate which were placed at bottom. For the purpose of combustion air has come from provided air holes and allow to pass through flue gas passage which further connected to Chimney. Air holes and flue gas passage were constructed in diagonal as shown in Figure 11. Also, Secondary air were come from feed hole which was used to feed bagasse for combustion. Heat transfer to pan take place from combustion heat in the form of Radiation and Convection. Then pan was supply heat to Jaggery making process in the convection mode.

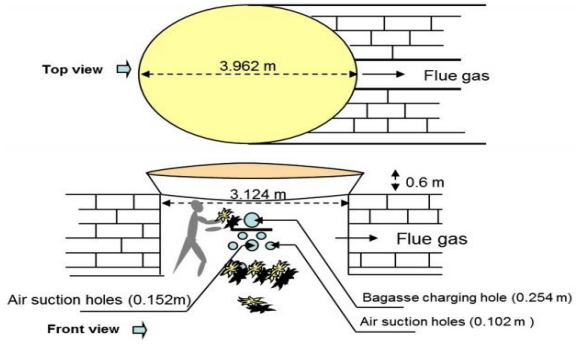

Fig. 11 – Detail of Single pan Jaggery plant furnace. [6]

From the operational survey of Single, double and four pan Jaggery plant, it was found that double pan and four pan Jaggery plant consumed less amount of bagasse for combustion compared with single pan Jaggery plant. To analysed this fact the CFD Model has prepared considering double pan and four Jaggery plant furnace as shown in Figure 12 & 13.

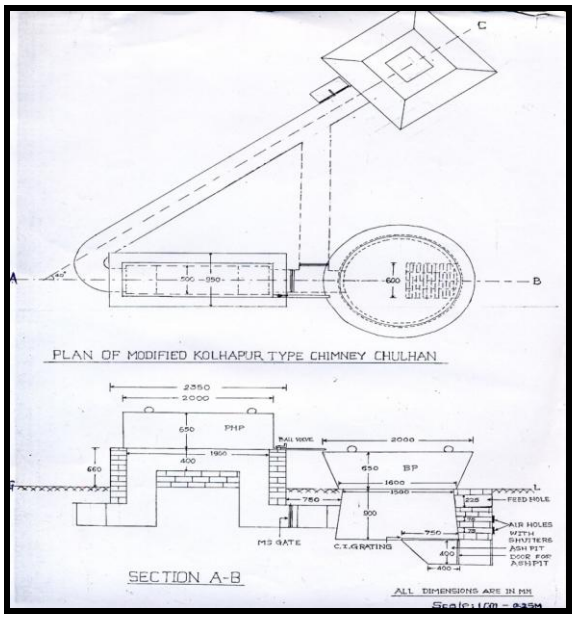

Fig. 12 – Detailed drawing of 2 Pan Jaggery Plant.

Figure 12 was a modified double pan Jaggery plant, which has two ways for flue gas flow towards chimney. It was also used as single pan, when only single batch to run for jaggery process. This design used bend angle of 40-45° for flue gas passage to control the velocity of hot gases going to chimney.

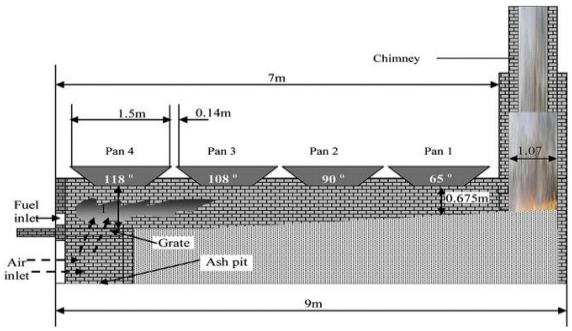

Fig. 13 – Furnace cross section of 4 pan Jaggery plant. [13]

In Figure 13, Four Pan jaggery furnace was shown. It has in-line pans of Jaggery making hence, flue gases passage was straight. But it has stepped chimney to restrict flue gas to utilised its heat.

The simple 2D model was prepared in ICEM CFD for double pan and four pan Jaggery making furnace as shown in figure 14 & 15. It was created only for furnace inside cavity which consist of flue gases. Air holes and feed holes was considered as pressure inlet and chimney top as pressure outlet. Furnace base considered as hot surface with combustion gas temperature which radiate heat to its surrounding.

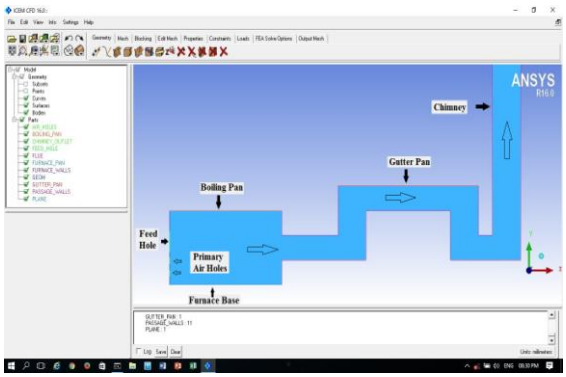

Fig. 14 – 2D CFD Model created in ICEM CFD of 2 pan Jaggery plant.

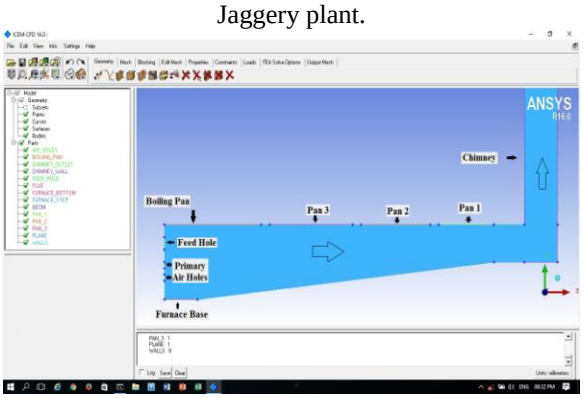

Fig. 15 – 2D CFD model created in ICEM CFD of 4 Pan

Jaggery Plant.

The Fluent solver has been used to simulate the above cases of double pan and four pan Jaggery plant. In the model setting, k-epsilon (2 equation) turbulent model has been selected. To solve energy equation of heat transfer, radiation model of Surface to Surface type has selected. For simulating Pressure and velocity SIMPLE solver has been used for Pressure based model.

In the next chapter, result of the above cases has been discussed with temperature contours to explain behaviors of flue gases inside the furnace and flue passage.

V. RESULTS & CONCLUSION

The Double pan & Four pan Jaggery plant furnace analyzed for flue gas flow nature of flow and its temperature which was carried out with it from combustion place to chimney exit. As shown in figure 16, temperature of furnace base was transfer to boiling pan through radiation, so that it was heated more for boiling of Jaggery Juice. Contours also shows that; the heat of furnace base and boiling pan was carried out by flue gas with help of air coming into combustion chamber. This hot gas gives convective heat to gutter pan for preheating of juice. Because of ups and downs in flue gas passage flow of flue gas restricted which help to recover heat of flue gas to gutter pan juice heating. Still some amount of hot gases goes to chimney.

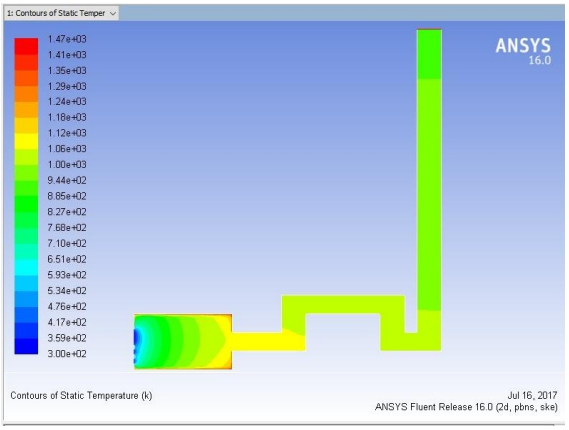

Fig. 16– Flue gas Temperature contours in 2 pan Jaggery plant

Figure 17, shows the temperature of flue gas at boiling pan and gutter pan compared with furnace base temperature.

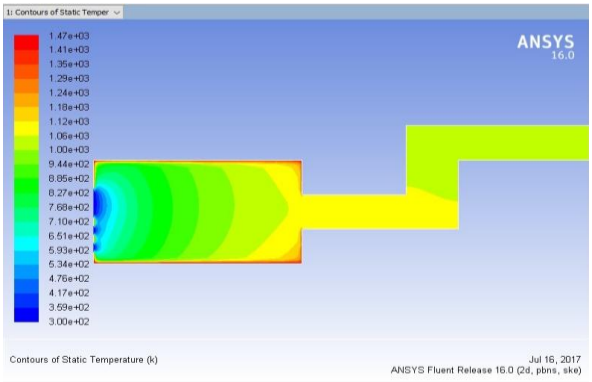

Fig. 17 – Temperature at furnace bottom, boiling pan and flue gas under gutter pan.

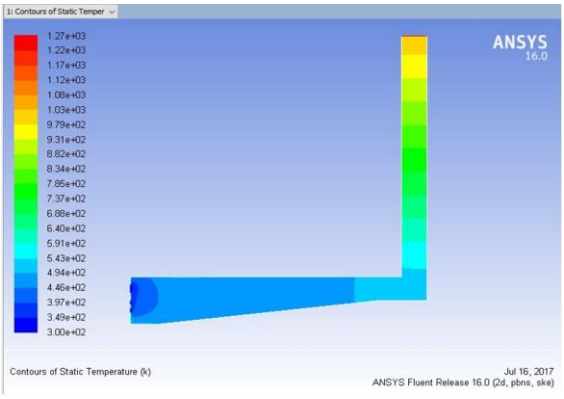

Fig. 18 – Temperature contours of flue gas in 4 Pan Jaggery Plant.

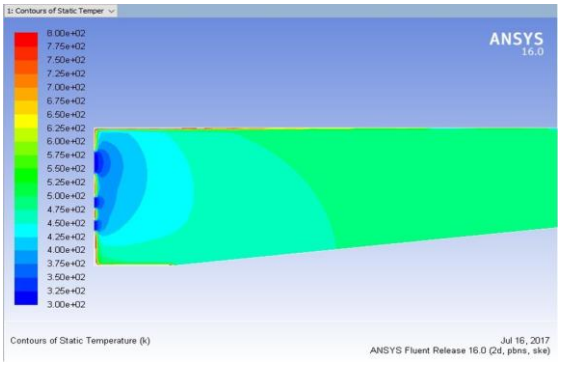

Fig. 19 – Temperature contours showing temperature at the surface of furnace with pans.

Because of simplified CFD model of 4 pan Jaggery plant furnace, figure 18 shows that, flue gases go very fast towards chimney with its temperature. Figure 19 shows, the comparison of temperatures of boiling pan and adjacent preheating pan with furnace base temperature. The furnace base radiate heat to the Jaggery pans.

Therefore, it is essential to improve overall performance of Jaggery plant by modification in construction of Furnace Pan, Chimney which resulted in saving in fuel and energy.

VI. FUTURE SCOPE

By the current CFD analysis, it has been clear that the combustion heat goes to boiling pan in the form of radiation heat and remaining heat goes with flue gas through chimney. So that as found in some type of Jaggery plant, they control flue gas flow at chimney. This work gives thread to further research in this way. Which has summarised as below,

1. Creating a prototype of furnace to measure the temperature of pans and flue gas.

2. Control of velocity by changing flow path of flue gas from combustion chamber to chimney.

3. Utilization of flue gas heat for preheating of juice with efficient furnace pan design.

REFERENCES

[1] A. K. Dwivedi, A. Mishra**,** A study on gur (jaggery) industry in India**,** www.indianmba.com/Faculty_Column/FC1053/fc1053.html;2010 [February 2010].

[2] Amit Kumar Dwivedi, An empirical study on gur (Jaggery) Industry (with special referenace to operational efficiency & profitability measurement), Research and publication, IIMA, India, W.P. No. 2010-12-03.

[3] G. N. Tiwari, Sanjeev kumar, Om Prakash, Study of heat & mass transfer from sugarcane juice for evaporation, Desalination, 159 (2003), pp. 81-96.

[4] H. K. Madan, U. K. Jaiswal, S. Kumar, S. K. Khanna**,** Improvement in gur (Jaggery) making plant for rural areas. Journal of Rural Technology, 2004; 1(4), pp.194-6.

[5] K. Sada Shiv Rao, A. Sampathraran, S. A. Ramjani, Efficiency of traditional jaggery making furnace, Madras Agriculture Journal, January-March 2003, 90(1-3):184-185.

[6] Kiran Y. Shiralkar a, Sravan K. Kancharla b, Narendra G. Shah a,□, Sanjay M. Mahajani, Energy improvements in jaggery making process, Energy for Sustainable Development 18 (2014) 36–48.

[7] Milind V. Rane, Siddharth K. Jabade, Freeze concentration of sugarcane juice in a jaggery making process**,** Applied Thermal Engineering, 25 (2005), pp. 2122-2137.

[8] R. D. Singh, B. Baboo, A. K. Singh, S. I. Anwar. Performance evaluation of two pan furnace for jaggery making**.** The Institute of Engineers Journal- Agriculture, 2009; 90, pp. 27-30.

[9] S. K. Das, PVK Jagannadha Rao, Madhusweta Das, Jaggery – A Traditional Indian A Sweetener, Indian Journal of Traditional Knowledge, January 2007, Vol. 6(1), pp. 95-102.

[10] S. I. Anwar, Fuel and energy saving in open pan furnace used in Jaggery making through modified juice boiling/concentrating pans. Energy Conversion and Management, 2010; 51: pp. 360-4.

[11] S. I. Anwar, Determination of moisture content of bagasse of Jaggery unit using microwave oven, Journal of Engineering Science and Technology, Dec 2010, Vol. 5(4), pp. 472-478.

[12] U. S. department of Energy, Waste heat reduction and recovery for improving Furnace efficiency, productivity and emissions performance, A Best Practices Process Heating Technical Brief, DOE/GO-102004-1975, November 2004.

[13] Vishal R. Sardeshpande, D.J. Shendage, Indu R. Pillai, Thermal performance evaluation of a four pan jaggery processing furnace for improvement in energy utilization, Energy, Dec 2010, Vol. 35(12), pp. 4740-47.

[14] Ghosh AK, Shrivastava AK, Agnihotri V. Production technology of lump sugar-gur/jaggery. New Delhi, India: Daya Publishing House; 1998.

[15] Lakshmi Pathi Jakkamputi, Mohan Jagadeesh Kumar Mandapati, "Improving the performance of Jaggery Making Unit using Solar Energy", Perspectives in science, (2016).

[16] Anil Kumar, G.N. Tiwari, Effect of shape and size on convective mass transfer coefficient during greenhouse drying (GHD) of Jaggery, Journal of Food Engineering 73 (2006) 121–134

[17] Mahesh Kumar, Effect of internal heating on sensible behavior of sugarcane juice in a stainless steel pot, Facta Universitatis, Series: Mechanical Engineering Vol. 10, No 2, 2012, pp. 113 – 124.

[18] Zailer Astolfi-Filho, Luis A. Minim, Javier Telis-Romero, Valeria P. R. Minim, and Vania R. N. Telis, Thermophysical Properties of Industrial Sugar Cane Juices for the Production of

Bioethanol, J. Chem. Eng. Data 2010, 55, 1200–1203.

[19] Raul La Madrid, Daniel Marcelo, Elder Mendoza Orbegoso, Rafael Saavedra, Heat transfer study on open heat exchangers used in jaggery production modules – Computational Fluid Dynamics simulation and field data assessment, Energy Conservation and Management, (2016).