Design & Model Fabrication of Brown Sugar Making Machine from Sugarcane Juice for Small Scale Farmers

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2022

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A Project Report Submitted to the Department of Mechanical Engineering in partial fulfilment of the requirements for the degree of Bachelor of Science in Mechanical Engineering

Faculty of Mechanical Engineering

National University Technology,

Islamabad, Pakistan

Aug,2023

BSME	**BILAL, ABDULLAH, ALI**	**2023**

CERTIFICATE OF APPROVAL

It is certified that the project titled “Design & Model Fabrication of Brown Sugar Making Machine from Sugarcane Juice for Small Scale Farming’ carried out by Muhammad Bilal, Reg. No. F19602028, Abdullah Butt, Reg. No. F19602001 and Ali Ehtesam, Reg. No. F19602034. under the supervision of Sajid Raza Zaidi, Lecturer, National University of Technology (NUTECH), Islamabad.

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ACKNOWLEDGMENT

All the acclamation and appreciations are for Almighty ALLAH who created the universe and bestowed the mankind with knowledge and wisdom to search for its secrets. We would like to thank all those who have supported and contributed to the successful completion of this project. We extend our gratitude to supervisor and co-supervisor, Sajid Raza Zaidi (Lecturer) and Engr. Khubaib Haider (Lab Engineer), Mechanical Engineering Department, National University of Technology (NUTECH), I-12, Islamabad, for their valuable guidance, support, and encouragement throughout the project. We would also like to say thanks to component and material manufacturers, and our friends and family for their support in completing this project.

The research project title “Design & Model Fabrication of Brown Sugar Making Machine from Sugarcane Juice for Small Scale Farmers” was successfully completed in the manufacturing processes lab in the mechanical engineering department of National University of Technology under the Pakistan Engineering Council (PEC) annual award of final year design projects (FYDPs) for the year 2022-2023. The project was supervised by Lecturer Sajid Raza Zaidi

DEDICATED

TO

OUR PARENTS,

TEACHERS

AND

PAKISTAN

ABSTRACT

This study presents an innovative project focused on the design and fabrication of a brown sugar making machine, aiming to revolutionize the sugar production process and empower farmers economically. This aimed at helping farmers become more financially stable. Instead of sending raw sugarcane, farmers can now directly transport brown sugar to sugar industries. This shift improves their economic situation and benefits the agriculture sector as a whole The core innovation of the project lies in the application of a novel concept: harnessing the flue gases generated during bagasse combustion for the purpose of pre-heating sugarcane juice. This ingenious approach serves to significantly augment the thermal efficiency of the sugar production process. Simulation results reveal an impressive pre-heating juice temperature of 72°C, while experimental findings reveal an impressive pre-heating juice temperature of 68°C. In comparison to the conventional methodology without pre-heating, the project showcases remarkable improvements. Prior to the implementation of pre-heating, the thermal efficiency was recorded at approximately 19%, with a substantial 4kg of bagasse consumed for brown sugar produced from 5L sugarcane juice. However, through the incorporation of the pre-heating process, a substantial enhancement in thermal efficiency to 36% was achieved, accompanied by a substantial reduction in bagasse consumption to 2.10kg, while maintaining an equivalent brown sugar output. In the experimental setup, a pre-heating temperature of 67°C was attained and by using pre heated juice, resulting in an overall increase of 21% in thermal efficiency compared to the traditional approach. Furthermore, the bagasse consumption rate was reduced by 1.95kg for the production of brown sugar from 5L of sugarcane juice. This project doesn't just change how we make sugar; it empowers farmers and shows how smart ideas can make farming better for everyone. It's a small step towards a stronger farming economy and a greener environment

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NOMENCLATURE

Mj	Mass of Juice
Mw	Mass of Water
Mbs	Mass of Brown Sugar
Mbag	Mass of Baggase
Vj	Volume of Juice
Cpj	Specific Heat Capacity of Juice
Cpbs	Specific Heat Capacity of Brown Sugar
CV	Calorific Value
Hfg	Heat of Vaporization of Water
ST	Striking Temperature

LIST OF FIGURES

Chapter 01

INTRODUCTION

1.1. Overview

Traditionally the sugar cane farmers transport their sugar cane to the sugar mills directly. Due to this reason the farmers have to bear a significant loading and transportation cost. In addition to this the loaded trucks have to wait outside the sugar mills for days. This decreases the weight of the sugar cane due to evaporation. Thirdly the sugar cane farmers have no access to sell their product into the market directly as it is not in finished shape (end product). And lastly the farmers cannot store the sugar cane at their facility as it need a lot of space.

It has been observed from the market survey that demand of brown sugar is increasing in the market due to health hazards associated with white sugar.

Keeping in view the current demands of the market and problems faced by the sugar cane farmers this project is proposed to solve the issues related to sugar cane transportation, to give a better profit to famers of sugar cane. In addition to this the farmers will be able to convert sugar cane juice into brown sugar in an efficient way.

Conventionally farmers use inefficient ways to make brown sugar which compromises its hygiene, taste and uses a lot of energy and time. In this project it is proposed to use heat and a spray mechanism in a hybrid formation for dehydration of sugar cane juice. This method will remove almost all the water/ moisture from the sugar cane juice and will convert it into brown sugar.

The farmers can then transport the brown sugar to sugar mills easily as it needs lesser transportation resources or can even sell it into the market directly. In addition to this the brown sugar can also be stored for a longer period of time as compared to sugar cane.

1.2. Problem Statement

Transportation of Sugar cane to sugar mills is labor intensive and expensive. Lose in weight in the form of evaporation of juice in sugar cane devalues it. The traditional method of removing moisture from sugarcane juice is inefficient and labor intensive which result in high production cost. Farmer cannot store sugarcane for a long period of time.

1.3. Purpose of Project

Purpose of this project is to efficiently convert sugarcane juice into the brown sugar with less heat losses and enable farmers to make brown sugar in field in efficient way with reduction in heat losses and supply brown sugar to sugar industries instead of sugarcane.

1.4. Specifications of Proposed Solutions

Our proposed solution system will have following specifications.

- Utilizing exhaust gases for preheating to increase thermal efficiency
- Using fins at bottom of boiling pan to increase heat transfer
- Thermal insulation to minimize heat losses

1.5. Brown Sugar Making Process

Brown Sugar making processing is one of the largest agriculture industry based project. It is a traditional form of sweetener produced and utilized in rural villages. From many decades' structure of traditional jaggery plant is still same. It contains big size pans which are used to boil juice of sugarcane. Heat is supplied to pans by furnaces. It is batch and traditional process with zero maintenance. It does be happening for almost 200 years and there is not much change in brown sugar making process.

Process of brown sugar making is almost same in every part of the sub-continent. Brown sugar making from the sugarcane is a traditional process which creates local employments and entrepreneurship opportunities. Brown sugar making plants are generally small units fabricated by local artisans on the basis of age old expertise without any technical support. It mainly consists of an underground furnace, with a pan mounted on to it for evaporating the juice. Following is the stepwise process of making brown sugar.

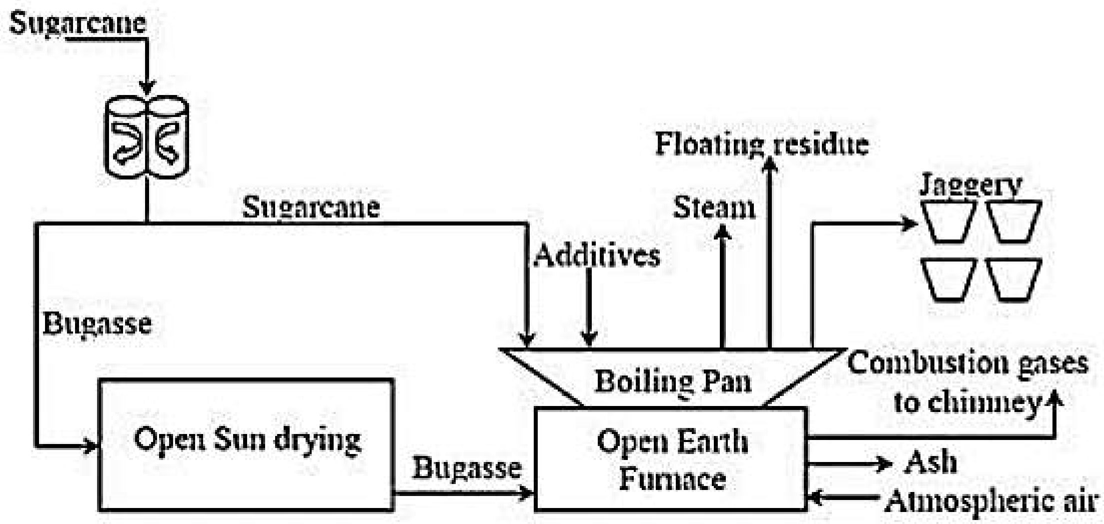
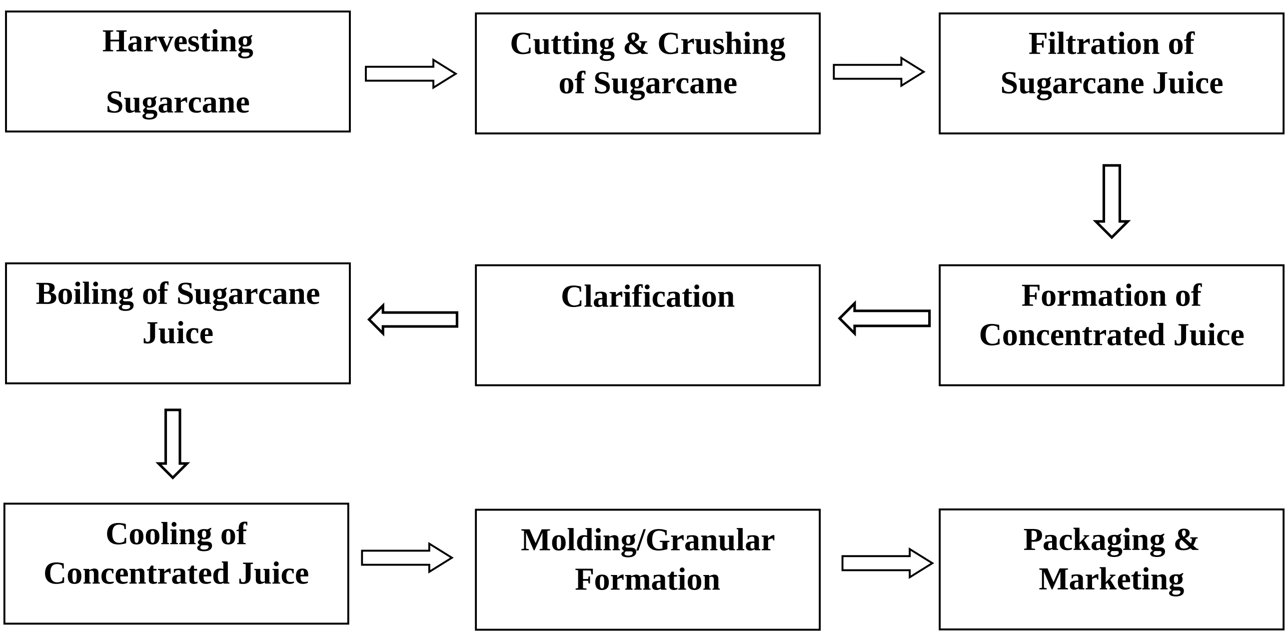


Figure1.1 Traditional Process of Brown Sugar Making Plant

Following is the stepwise process of making brown sugar.



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- **Harvesting Sugarcane**

Harvesting of sugarcane is the first step and important activity for yielding of sugarcane juice. Maturity of sugarcane is most essential to achieve good quality and maximum extraction of juice from sugarcane. This process is done manually by labors that increases the plant cost. In India harvesting of sugarcane is carried out in 10 to 18 months[1].

- **Cutting and Crushing of Sugarcane**

Matured sugarcane crushed by electric motor or diesel engine operated crushers. In ancient this work was done by Bullock. Depending upon the capacity of plant different, two rollers, three rollers and three rollers with gear box system crushers are being used in jaggery production plants. After crushing of sugarcane, the juice is collected in the settling tank through pipe line and then it is transferred to the boiling pan for heating. The crushing efficiency of vertical crusher varies from 50-55%[2].

- **Filtration of Sugarcane Juice**

The bigger size impurities present in the extracted juice were separated with a muslin cloth; then the juice is transferred into the settling tank and allowed to settle for few minutes. The lighter waxy particles float on the juice surface while the clear juice was collected through the tap from the bottom of the settling tank.

- **Boiling and Clarification of Sugarcane Juice**

Fresh sugarcane is heated in open pans of different types of traditional jaggery making plants. The pans used are made of mild steel. The furnace is made up of masonry brick cemented with clay. Different sizes and numbers of pans are used according to the capacity of plant. In these plants bagasse is being used as fuel. During boiling, purification of juice is also done by adding clarificants and additives to remove impurities. Conventionally organic (okra powder, lime and bhendi) and inorganic (sodium carbonate, sodium bicarbonate and sodium hydrosulphide) clarificants are used for this purpose. The process of concentration of juice takes place up to the striking point temperature (118°C to 120°C) after which no further heating is required. After concentration a semi-solid product is obtained known as jaggery[3].

- **Cooling of Concentrated Juice**

The concentrated product obtained after concentration of juice is cooled and molded. During molding finished product is obtained in different shapes and sizes according to its final use. The shape of the final jaggery may be cubic, rectangular, trapezoidal or bucket size in different weights according to use**[4].**

- **Packaging and Marketing**

After formation of brown sugar, we can directly pack it and can sell it in the market. We can sell granular form brown sugar to sugarcane industries.

Figure 1.2 Traditional Jaggery Making Plant

1.6. Advantages

Following are the advantages of this project

- It'll create rural employment.
- Enable farmers to be economically stable
- Reduction in transportation charges for farmers
- Less heat losses.

Chapter 02

LITERATURE REVIEW

At present, 115 countries of the world cultivate sugarcane for sugar production and produce about 133 million tonnes of sugar and 10 million tonnes of brown sugar. Brazil, India, China, Pakistan, USA, Australia, Thailand and Philippines are some major sugarcane cultivating countries in the world. On an average, 15-20 percent sugarcane is utilized for brown sugar production[5]. Brown sugar is the most popular traditional sweetener produced by concentration of sugarcane juice without the separation of molasses. Organic brown sugar is prepared without the use of any chemical/ synthetic additives. The color of brown sugar varies from golden brown to dark brown but from market point of view light golden colored brown sugar is very popular. Brown sugar is produced all over the world under different names[6]. To prepare solid brown sugar the clarified sugar cane juice is boiled at its striking point temperature varying from 116 to 120 °C and then filled in to the molds of different shapes and sizes. The moisture contents of solid jaggery lies in between 5% and 7%[7] . The liquid brown sugar is semi liquid syrup made by boiling of sugarcane juice below striking point temperature varying from 105 to 108 °C[8]. It contains 30–36% water, 40–46% sucrose, 15–25% invert sugar and 0.30% calcium[9]. The granular jaggery is prepared by rubbing the concentrated product of sugarcane juice with wooden scrappers to form grains instead of molding[10]. The striking point temperature for granular jaggery ranges from 120 to 122 °C and it contains about 1.65% water and 88.6% sucrose[10]. The market value of brown sugar is much affected by appearance parameters like color, texture, and smell of jaggery. The brown sugar marketing can provide a good marketing response on the basis of availability, price and season to the end-use[11]. The main cost of brown sugar production is around 50% of total cost, which is followed by labor cost, material cost, marketing cost and interest[12].

Elements of Traditional Brown Sugar Manufacturing Process

The basic elements used in traditional brown sugar manufacturing process are sugarcane juice, bagasse, and clarificant. Sugarcane juice is an opaque liquid available in different colors from gray dark green to light yellow depending upon the variety of canes used [2].The cost of bagasse as a fuel is one third of the other available fuels. Thus it plays an important role in the economic development of rural areas in which jaggery making units and sugar plants are established[13].

Clarificants are the organic and inorganic elements that are used to clarify the raw sugarcane juice in jaggery making process. Among the herbal clarificants used for the jaggery making the bhendi mucilage significantly contributed in removing higher amount of scum and highest non reducing sugars (83.56%) and significant decrease in the reducing sugars (4.44%) due to beneficial in reducing the inversion process. Use of bhendi mucilage, soyabean seed meal improved the colour of jaggery[14]. From the above discussion it is observed that sugarcane juice, bagasse, and clarificants are the major elements of a brown sugar making plant.

Operations of Traditional Brown Sugar Manufacturing Process

The first step of jaggery manufacturing operation is the weighing of cane and then transferred for the extraction of sugarcane juice by crushing it in a crusher[2]. The crushed sugarcane juice is then stored in a masonry settling tank and left for some time to separate the heavier impurities under the process of plain sedimentation. The clean sugarcane juice taken from the settling tank is transferred to the boiling pan where it is heated along with continuous stirring operation. Clarification is the process in which impurities are removed from sugarcane juice. The quality of jaggery depends on the type of clarificants used and the clarification efficiency of sugarcane juice[15]. Bhendi powder, bhendi mucilage and groundnut milk can be as herbal clarificants[16]. It was found that these clarificants are more efficient for maintaining the quality of jaggery than the other herbal and synthetic clarificants[17][18]. The effectiveness of juice clarification plays an important role in maintaining the quality and storage life of jaggery[19]. Sulfur dioxide is most popular clarificants agent that may produce sulphates and organo-sulfur which are hazardous for human beings[20]. The addition of lime in sugarcane juice improves the consistency of jaggery by increasing crystallization of sucrose, but the excess addition of lime can darken the color of final product[21]. The use of copolymers as a clarificants after liming decreases the clarification time which results in reduction of sucrose inversion, organic acid, reducing sugars, and helps in the formation of colored elements[22]. The quality of jaggery depends on the type of clarificants used and the clarification efficiency of sugarcane juice[23]. After heating and clarification, the concentrated product is transferred to the wooden/ aluminum molds mesh or to a wide open earthen pan for cooling. At the end of jaggery manufacturing process the finished product molded in different shapes[6].

From the above discussions it is observed that the complete jaggery manufacturing process is a continuous and systematic process starting from the crushing of sugarcane in a crusher, settling of juice in a tank, preheating of juice in a gutter pan, clarification of juice, and boiling of juice by using bagasse as a fuel. Herbal clarificants are found more efficient but increase the preparation cost of jaggery by 25%[6].

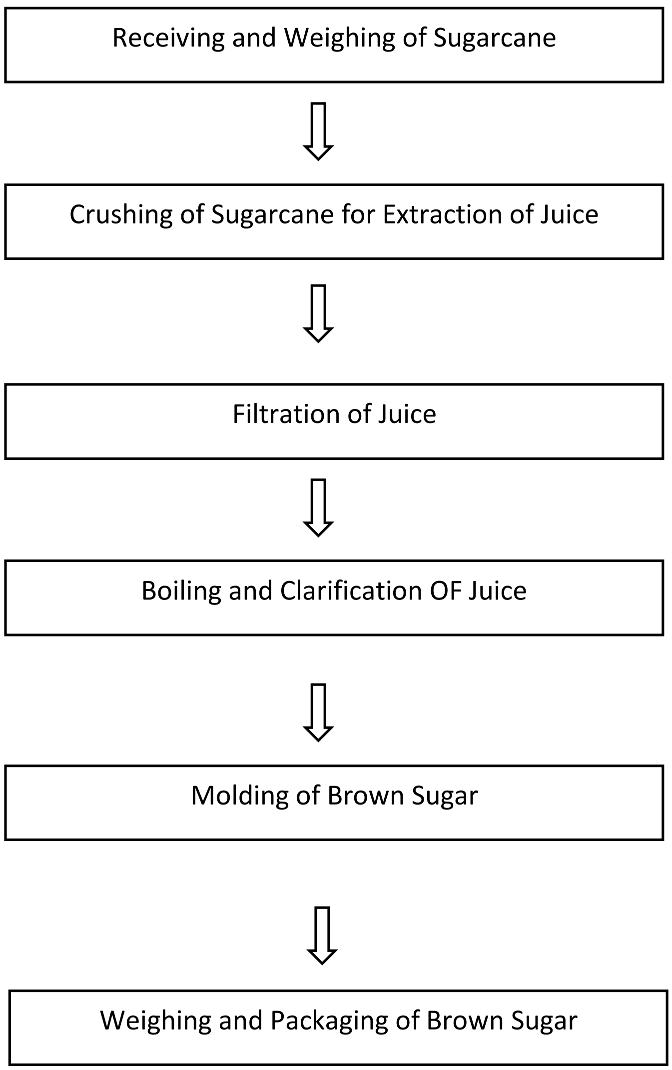


Figure 2.1 Flowchart of Brown sugar Manufacturing

2.1. Related Techniques

As our project is related to traditional way of making brown sugar. So, there are different traditional techniques uses to make brown sugar. Jaggery processing plants are constructed by local farmer at their field or farm. The production of jaggery starts from the harvesting of sugarcane to the extraction of juice, processing and clarification of juice for its concentration, cooling and molding[24]. According to these modifications and variations the following method are used;

2.1.1. Single Pan Brown Sugar Making Plant

Single pan Jaggery production method was used in ancient time in which one pan was used for the heating, clarification and concentration of the juice. The pan was directly placed over a pit type furnace made in the ground with rock stones and clay[25]. The process of making brown sugar using single pan is using almost everywhere nowadays. The traditional single pan jaggery manufacturing plant has very low value of thermal efficiency (14.75%) and high value of bagasse consumption (3.85 kg per kg of jaggery produced)[26] . The low efficiency of traditional jaggery making plant is due to partial crushing of sugarcane in a crusher and the use of open pan for the concentration process of jaggery[27].

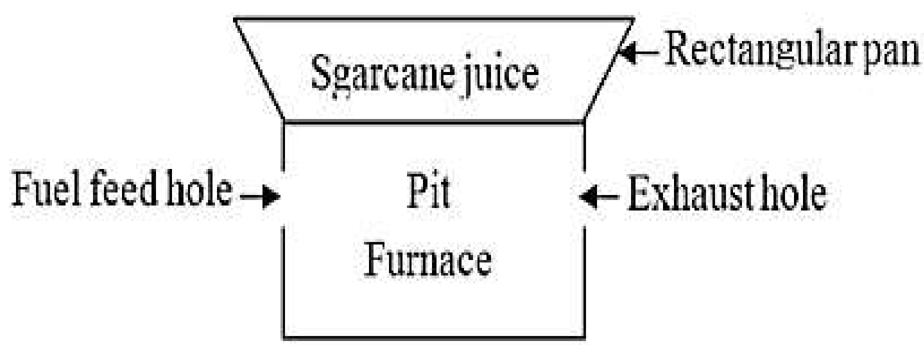


Figure 2.2 Schematic View of Single Pan Jaggery Making Plant

2.1.2. Two Pan Brown Sugar Making Plant

In two pan plant, a second pan is used for the preheating and clarification of juice before its final concentration in the main pan. Both the pans are placed in series over the furnace to utilize maximum thermal energy of flue gasses[24]. A second pan (gutter pan) in the way of hot flue gasses after boiling pan of a traditional jaggery making plant to improve its thermal efficiency[28]**.**The thermal efficiency of a two-pan jaggery processing was 29.3 % which was higher than single pan furnace[29][30].

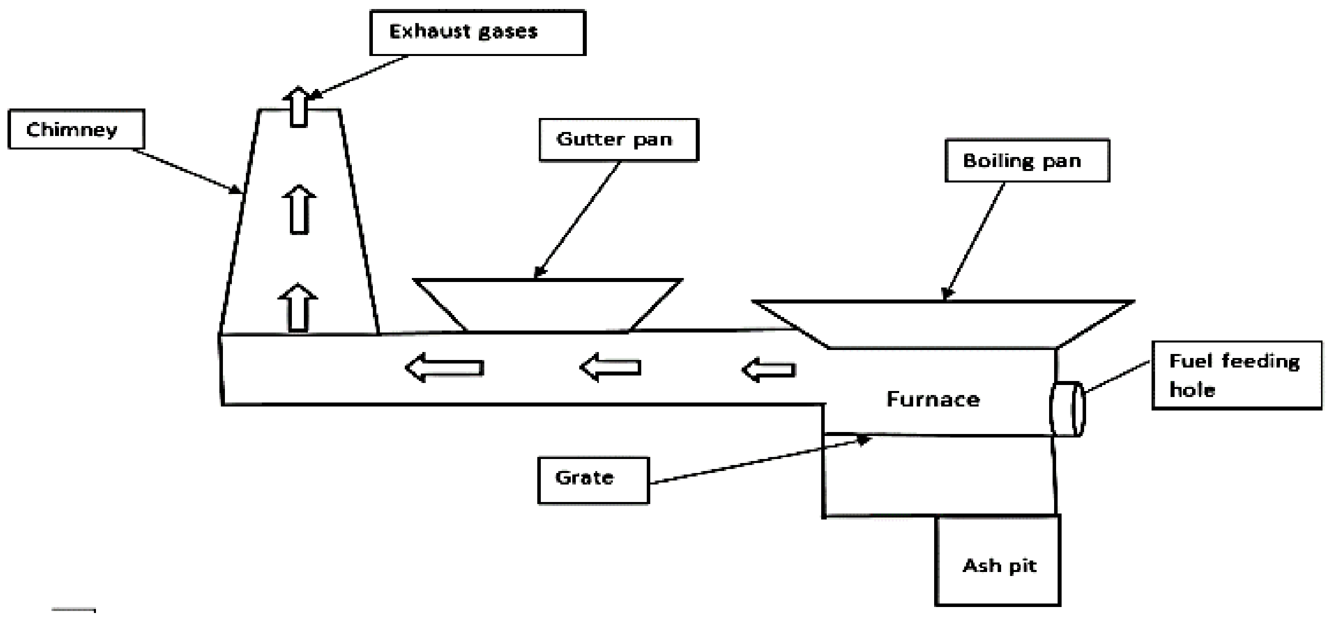


Figure 2.3 Schematic View of Two Pan Brown Sugar Making Plant

2.2. Related Projects

2.2.1. Multiple Pan Brown Sugar Making Plant

In such plant more than two pans are used for making brown sugar. One pan is the boiling pan and other pans are known as gutter pan which are used for preheating of sugarcane juice through exhaust gasses. A comparative trial was carried out on existing and improved three-pan jaggery making plants. It was observed that the specific bagasse consumption of traditional three-pan jaggery making plants can be improved from 2.24 kg to 1.96 kg per kg of jaggery produced by using fire-bricks with refractory cement, circular cross-section and optimum height of chimney, firing platform and fire grate[31]. The thermal performance of a four-pan jaggery making plant and observed that the consumption of bagasse reduced from 2.39 kg to 1.73 kg per kg of jaggery prepared[32]. The performance of multi-pan plant over traditional jaggery making plant and observed that it was better option for the utilization of fuel and quickness in boiling of sugarcane juice as compared to traditional single pan plant[33].

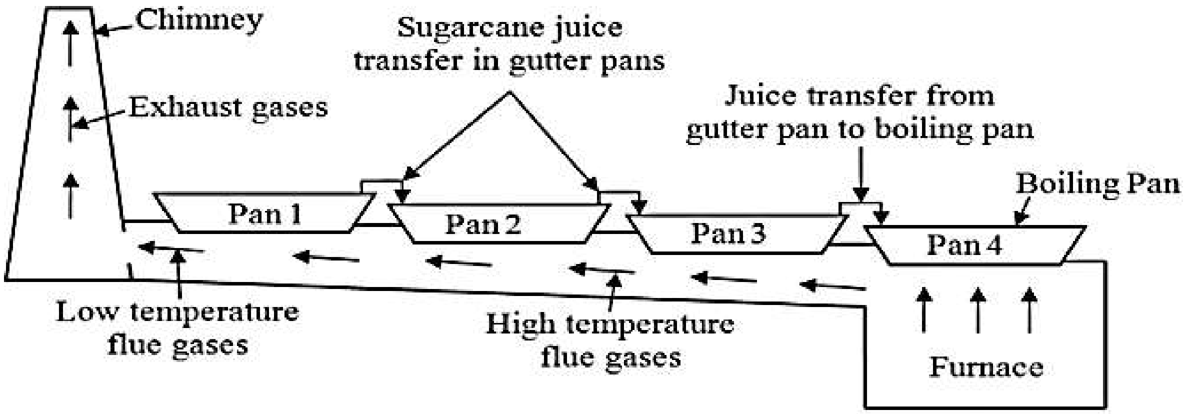


Figure 2.4 Schematic View of three Pan Brown Sugar Making Plant

2.3. Related Studies/Research

Different researches studied about traditional brown sugar making process and give their ideas about improving its efficiency. Some of the related researches are following;

2.3.1. Concept of Pre-Heating Sugarcane Juice for Performance Improvement

In order to reduce the losses and cut down the consumption of bagasse, exhaust heat is utilized for preheating of sugarcane juice in pre-heater. The improved plant and the conventional plant are compared on the basis of thermal efficiency and bagasse consumption per Kg jaggery production. Resulted that thermal efficiency is improved from 16.16% to 24.36% and bagasse consumption is reduced by 1.2 Kg per Kg jaggery production[5].

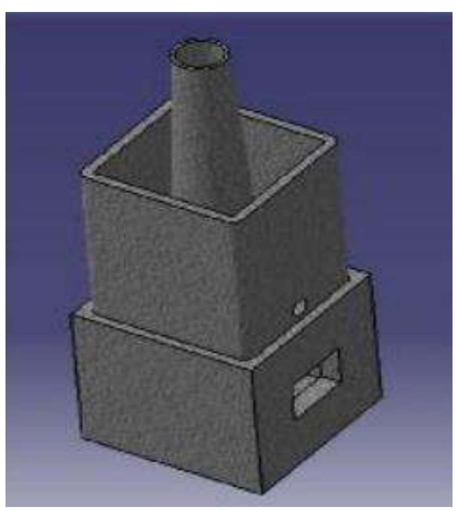


Figure 2.5 Modified Chimney Pre-Heater

The thermal efficiency of the traditional jaggery making plant can be increased and bagasse consumption can be decreased by the implementation of a pre-heater and economizer for preheating of sugarcane juice[34]. A three-pan jaggery manufacturing plant was fabricated for the better utilization of thermal energy of hot flue gases which resulted in good heat utilization efficiency of about 34.3%[35]. A comparative performance trial on existing and improved three-pan jaggery making plants. It was observed that the specific bagasse consumption of traditional three-pan jaggery making plants can be improved from 2.24 kg to 1.96 kg per kg of jaggery produced by using fire-bricks with refractory cement, circular cross-section and optimum height of chimney, sliding dampers, firing platform and fire grate[36].

2.3.2. Use of Fins for improving thermal efficiency

Different researchers use fins to improve thermal efficiency of traditional brown sugar making plant and give their results accordingly.

The concept of fins has been used for heating purpose for improving efficiency of open pan jaggery making furnace. Fins were provided to the bottom of main pan and gutter pan. Choice for type of fins was based on movement of flames and hot flue gases generated due to combustion of bagasse. Fins helped in more heat transfer to the sugarcane juice being concentrated. The use of fins and baffle at the bottom of single pan plant improve the thermal efficiency of plant by 9.44% along with the saving of fuel and energy by 31.34% as compared to traditional plant [37]. The use of fins at the bottom of boiling pan of a prototype model of traditional single pan jaggery making plant can increase the thermal efficiency of the plant from 15.35% to 24.50% and decrease the bagasse consumption from 3.83 kg to 2.75 kg per kg of jaggery produced[38].

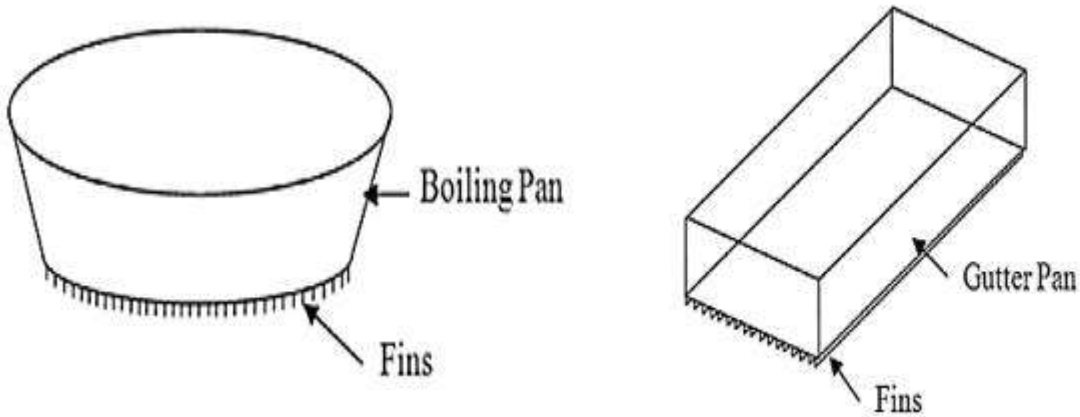


Figure2.6 Schematic views of fins at the bottom of boiling and gutter pan.

Figure 2.7. Modified traditional main pan and gutter pan.

2.4. Limitations and Bottlenecks

The main limitations of all the traditional process that are used still now is that there occurs a large amount of heat losses which reduces the thermal efficiency of the overall system. Due to this large amount of consumption of fuel occurs. Due to heat losses this process takes large amount of time to be completed. Another source of heat losses is that there is improper thermal insulation.

2.5. Summary of Literature Review

The traditional method used for making brown sugar has very less efficiency of 14.75%. But, by utilizing exhaust gases for pre heating the thermal efficiency increases from 15.35% to 24.50%. A lot of energy is wasted due to heat losses. When fins were used at bottom of boiling pan then it is observed that thermal efficiency was increased (Experimental Analysis). From this point of view our we can say if we use concept of pre heating sugar cane juice and fins then we can increase thermal efficiency of our system. Summarizing this our system will have following specifications.

- Utilizing exhaust gases for preheating to increase thermal efficiency
- Using fins at bottom of boiling pan to increase heat transfer
- Thermal insulation to minimize heat losses

Chapter 3

MATHEMATICAL MODELING AND DESIGN

3.1. Mathematical Modeling

3.1.1. Mass Calculation Equations

Following are different mass that we need to calculate in our system

- **Mass of Juice in Boiling Pan**

$$\mathrm{Mj} = \mathrm{Vj}(\mathrm{\rho j})$$

$$\mathrm{Mj} = 5(1.184)$$

$$\mathbf{Mj = 5.92Kg}$$

- **Mass of Water Evaporated in Boiling Pan**

$$\mathrm{Mw} = \%\ \mathrm{Concetration\ of\ water\ in\ juice} * \mathrm{Mj}$$

$$\mathrm{Mw} = 0.70 * 5.92$$

$$\mathbf{Mw = 4.14\ Kg}$$

- **Mass of Brown Sugar**

$$\mathrm{Mbs} = \mathrm{Mj} - \mathrm{Mw}$$

$$\mathrm{Mbs} = 5.92 - 4.14$$

$$\mathbf{Mbs = 1.78\ Kg}$$

3.1.2. Thermal Efficiency of Traditional Method

Thermal efficiency of making brown sugar by traditional method is calculated by following method.

- **Sensible Heat Energy of Water**

$$Qsensible = Mj * Cpj * (T\ evap - Tamb)$$

$$Qsensible = 5.92 * 3.47 * (100 - 25)$$

$$\mathbf{Qsensible = 1540.7Kj}$$

- **Latent Heat Energy of Water**

$$Q\ latent = Mw * hfg$$

$$Q\ latent = 3.97 * (2676 - 419.06$$

$$\mathbf{Q\ latent = 8960\ Kj}$$

- **Heat Energy Required to Reach Striking Point Temperature of Brown Sugar**

$$Qst = Mbs\ Cpbs\ (Tst - Tevap)$$

$$Qst = 1.95 * \ 2 * \ (118 - 100)$$

$$\mathbf{Qst = 70.2\ Kj}$$

- **Total Heat Energy of Juice**

$$Qbs = Qsensible + Q\ latent + Qst$$

$$Qbs = 1540.7 + 8960 + 70.2$$

$$\mathbf{Qj = 10570.9\ Kj}$$

- **Heat Energy Produces by Burning of Bagasse by**

$$Q\ bag = Mbag\ C.Vbag$$

$$Q\ bag = 5.25 * 14000$$

$$\mathbf{Q\ bag = 73500\ Kj}$$

So. Thermal efficiency will be

$$\eta = \frac{\text{Qj}}{\text{Qbag}} * 100$$

$$\eta = \frac{10570.9}{73500} * 10$$

$$\boldsymbol{\eta = 0.144 \text{ or } 14.3\%}$$

3.1.3. Thermal Efficiency Without Pre Heater

Thermal efficiency without using pre heater is calculated by following method.

- **Sensible Heat Energy of Water**

$$\text{Qsensible} = \text{Mj} * \text{Cpj} * (\text{T evap} - \text{Tamb})$$

$$\text{Qsensible} = 5.92 * 3.47 * (100 - 25)$$

$$\mathbf{Qsensible = 1540.7Kj}$$

- **Latent Heat Energy of Water**

$$\text{Q latent} = \text{Mw} * \text{hfg}$$

$$\text{Q latent} = 3.97 * (2676 - 419.06)$$

$$\mathbf{Q\ latent = 8960\ Kj}$$

- **Heat Energy Required to Reach Striking Point Temperature of Brown Sugar**

$$\text{Qst} = \text{Mbs Cpbs} (\text{Tst} - \text{Tevap})$$

$$\text{Qst} = 1.95 * 2 * (118 - 100)$$

$$\mathbf{Qst = 70.2\ Kj}$$

- **Total Heat Energy of Juice**

$$\text{Qbs} = \text{Qsensible} + \text{Q latent} + \text{Qst}$$

$$Qbs = 1540.7 + 8960 + 70.2$$

$$\mathbf{Qj = 10570.9\ Kj}$$

- **Heat Energy Produces by Burning of Bagasse by**

$$Q\ bag = Mbag\ C.Vbag$$

$$Q\ bag = 4 * 14000$$

$$\mathbf{Q\ bag = 56000\ Kj}$$

So thermal efficiency will be;

$$\eta = \frac{Qj}{Qbag} * 100$$

$$\eta = \frac{10570.9}{56000} * 10$$

$$\mathbf{\eta = 0.188\ or\ 18.8\%}$$

3.1.4. Thermal Efficiency with Preheater

- **Sensible Heat Energy of Water**

$$Qsensible = Mj * Cpj * (T\ evap - Tamb)$$

$$Qsensible = 5.92 * 3.47 * (100 - 25)$$

$$\mathbf{Qsensible = 1540.7Kj}$$

- **Latent Heat Energy of Water**

$$Q\ latent = Mw * hfg$$

$$Q\ latent = 3.97 * (2676 - 419.06)$$

$$\mathbf{Q\ latent = 8960\ Kj}$$

- **Heat Energy Required to Reach Striking Point Temperature of Brown Sugar**

$$Qst = Mbs\ Cpbs\ (Tst - Tevap)$$

$$Qst = 1.95 * \ 2 * \ (118 - 100)$$

$$\mathbf{Qst = 70.2\ Kj}$$

- **Total Heat Energy of Juice**

$$Qbs = Qsensible + Q\ latent + Qst$$

$$Qbs = 1540.7 + 8960 + 70.2$$

$$\mathbf{Qj' = 10570.9\ Kj}$$

- **Heat Energy Produces by Burning of Bagasse by**

$$Q\ bag = Mbag\ C.Vbag$$

$$Q\ bag = 2.10 * 14000$$

$$\mathbf{Q\ bag = 29400\ Kj}$$

So thermal efficiency will be;

$$\eta = \frac{Qj}{Qbag} * 100$$

$$\eta = \frac{10570.9}{29400} * 10$$

$$\mathbf{\eta' = 0.364\ or\ 36.4\%}$$

3.2. CAD Design Parts

Following procedure is applied to make CAD design.

Software Commands:

There are some commands which are used in our design

- Sketch
- Extrude
- Sweep
- Lofted Boss Base
- Fillet
- Chamfer
- Delete
- Shell
- Hole
- Extrude Cut
- Dimension modification
- Equal
- Arc
- Circle
- Ellipse
- Rectangle
- Line
- Mirror
- Pattern
- Reference Plane

3.2.1. Heat Exchanger Design

Heat Exchanger shell is designed using Solidworks. Steps followed in design are following

- Sketch a pattern using line tool. .

- Now add a reference plane on the any of the ne end of the sketch using reference geometry feature.
- Now sketch a rectangle of given dimension on the reference plane.
- Now by using the sweep command select the rectangle as the profile and the pattern sketch as the path.
- Now using the shell command select the top face of the whole body and shell using 2mm thickness.
- Now create a plane on one end of the sketch that is 25mm offset and draw a circle of required diameter.
- Select the loft command and add the rectangle sketch and the newly made circle sketch in profile and creates the profile.
- Make a plane in the centre of the body parallel to both of the sides.
- Using the mirror geometry command mirror the lofted body to the other side using the newly made plane as mirror plane.

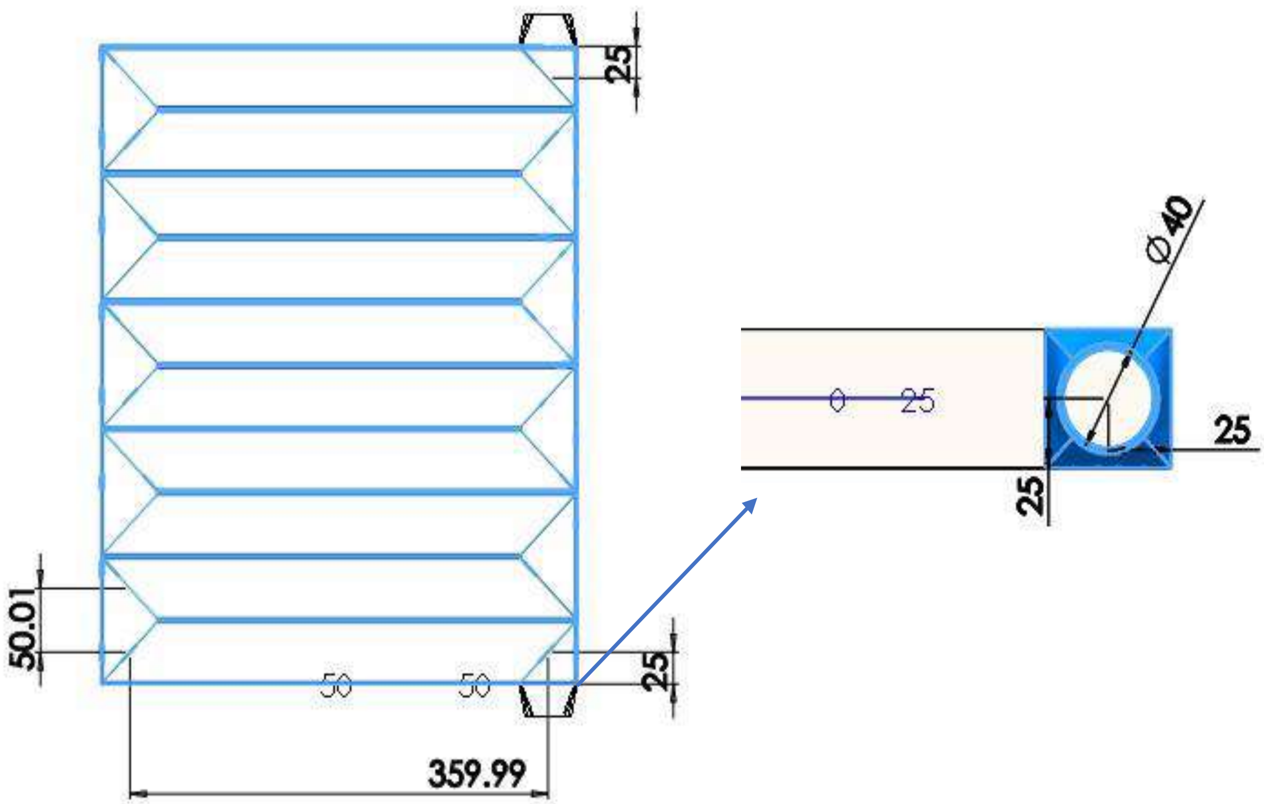


Figure 3.1. Sketch Design of Pre Heater

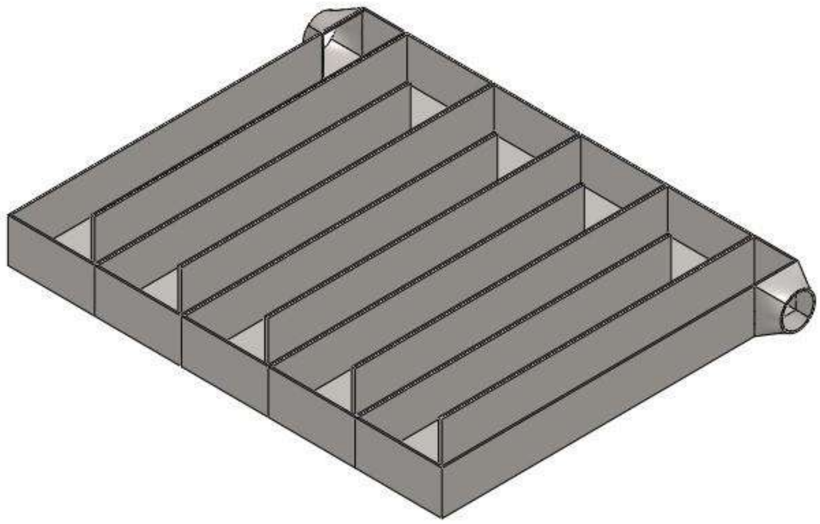


Figure3.2. Design of Pre Heating Chamber of Heat Exchanger

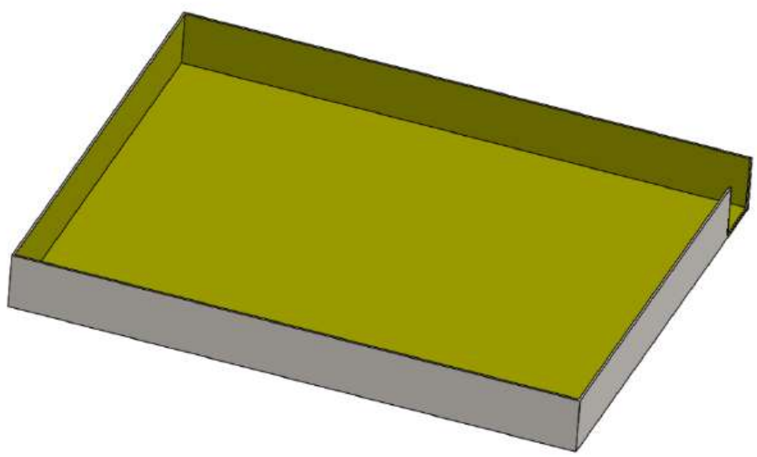


Figure 3.3. Design of Boiling Pan of Heat Exchanger

3.2.2. Furnace design:

Heat Exchanger shell is designed using Solidworks. Steps followed in design are following

- Sketch a rectangle of the given dimensions.
- Extrude the sketch to the given height.
- Make a shell using the thickness of 2mm.
- Create a reference place on the top of the open face of the furnace.
- Now sketch a rectangle of given dimension on the both edges of the top face of the furnace.
- Now extrude the rectangles to 2mm thickness to create a resting edge for the boiling container.
- Now create a plane on one the both sides of the furnace.
- On the right side extrude cut a circle of diameter 40 mm for the exhaust outlet.
- On the left side extrude cut an opening for the air inlet for burning at the bottom.
- Make a door using a rectangle and extrude cutting it for fuel inlet.

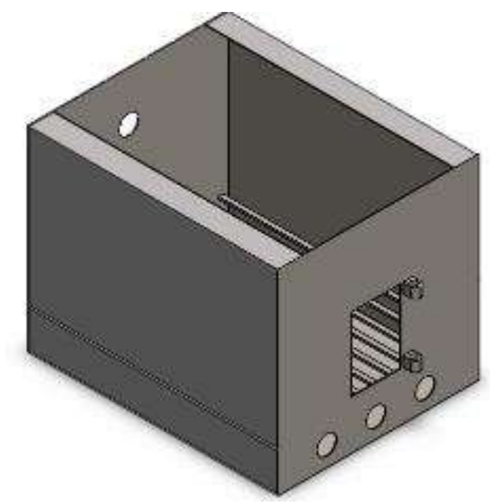


Figure 3.4. 2D Design of Furnace

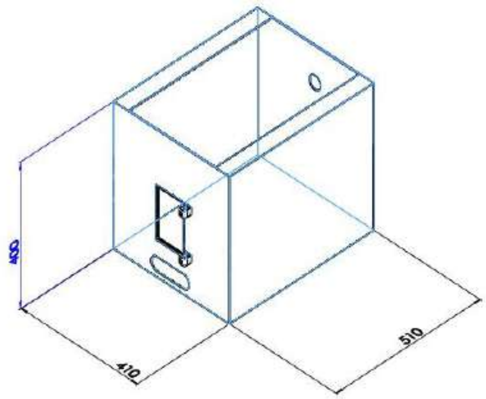


Figure 3.5. Side View Sketch Design of Furnace

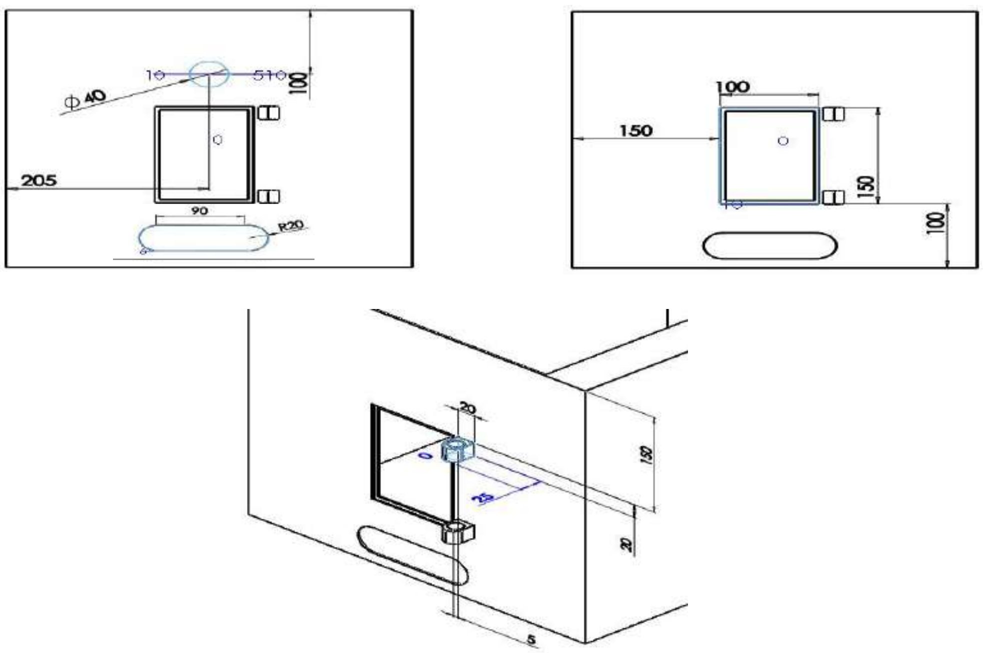


Figure 3.6. Sketch Design of Furnace

3.2.3. Boiling container design

Boiling container is designed using Solidworks. Steps followed in design are following

- Sketch a rectangle of the given dimensions.
- Extrude the sketch to the given height.
- Make a shell using the thickness of 2mm.

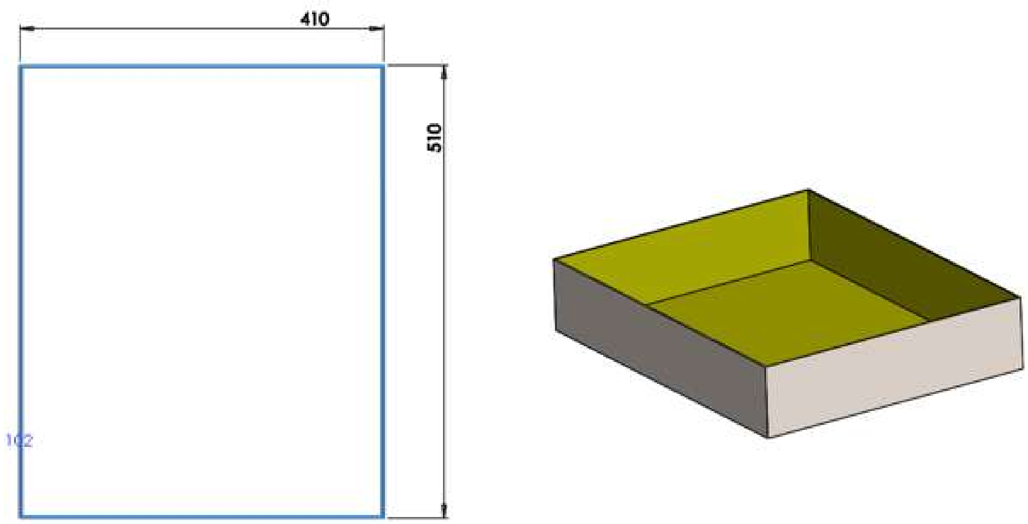


Figure 3.7: Sketch and 2D Design of Boiling Pan

3.3. Specification of Designed Parts

3.3.1. Specifications of Boiling Pan

1) Material of Boiling Pan

Boiling pan is made up of non-magnetize 304 stainless steel material because of several reasons;

- **Corrosion resistance**: Due to its outstanding corrosion resistance 304 stainless steel is suited for use in a variety of applications that include food.
- **Hygienic properties:** Its hygienic qualities make it a popular option in food processing and handling equipment. It is also simple to clean and maintain.
- **Non-reactivity:** Because 304 stainless steel doesn't react with the majority of food ingredients, it won't interact with or contaminate the food being prepared or stored.
- **Strength and toughness:** This kind of stainless steel is renowned for its great strength and toughness, which enable it to handle the demands of activities in the food sector.
- **Aesthetics**: It has a nice, polished surface that improves the aesthetic attractiveness of the serving and food preparation equipment.
- **Non-porous surface:** 304 stainless steel has a non-porous surface that keeps out odors and germs from growing by not absorbing food particles, liquids, or stains.

- **Resistance to staining**: It is stain-resistant, ensuring that the equipment keeps its look even after extended contact to food-related contaminants.
- **Food safety compliance:** 304 stainless steel satisfies or surpasses legal requirements for materials in contact with food, making it safe for use in the food sector.
- **Versatility:** This kind of stainless steel is simple to mould into a variety of shapes and sizes, enabling customization based on particular food processing or storage demands.

Figure 3.8: Stainless Steel Boiling pan

2) Dimensions of Boiling Pan

It is important to choose a pan that is appropriately sized for the volume of liquid being boiled. A pan that is too small can cause the liquid to boil over. So, keeping in view appropriate boiling the boiling pan size is 17 inches' length, 17 inches width and inches width which is enough to boil 5L sugarcane juice.

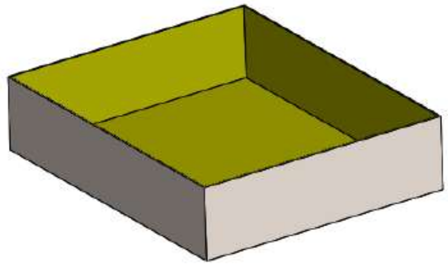


Figure 3.9: Boiling pan

3.3.2. Specifications of Preheating Exhaust Gas Chamber

1) Material of Exhaust Gas Chamber

Heat Exchanger exhaust utilization section will be made up of stainless steel material because of several reasons;

- Corrosion resistance
- Heat resistance
- High strength and durability
- Easily Cleanable

2) Purpose of Exhaust Gas Chamber

We designed a heat exchanger to exchange maximum heat between the exhaust gasses and the juice to pre heat so it can make the process heat efficient. In this exchanger we made a pathway for the exhaust to maximize the time its stays in the exchanger and exchange more heat

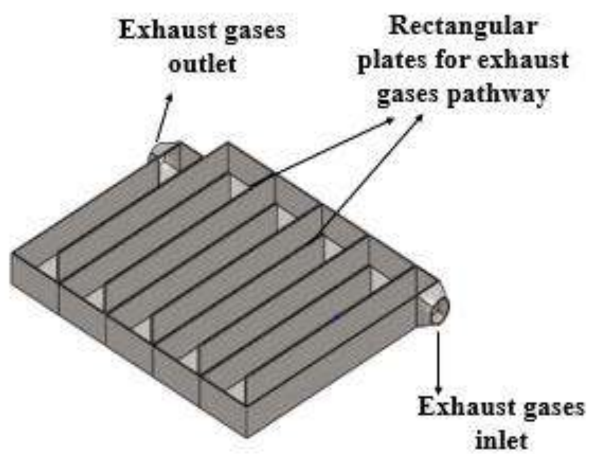


Figure 3.10: Pre Heater Exhaust Chamber

3.3.3. Specifications of Pre Heating Boiling Pan

1) Material of Preheating Boiling Pan

Boiling pan is made up of non-magnetize stainless steel material because of several reasons;

- **Corrosion resistance**: Due to its outstanding corrosion resistance stainless steel is suited for use in a variety of applications that include food.
- **Hygienic properties:** Its hygienic qualities make it a popular option in food processing and handling equipment. It is also simple to clean and maintain.
- **Non-reactivity:** Because stainless steel doesn't react with the majority of food ingredients, it won't interact with or contaminate the food being prepared or stored.
- **Strength and toughness:** This kind of stainless steel is renowned for its great strength and toughness, which enable it to handle the demands of activities in the food sector.
- **Aesthetics**: It has a nice, polished surface that improves the aesthetic attractiveness of the serving and food preparation equipment.
- **Non-porous surface:** 304 stainless steel has a non-porous surface that keeps out odors and germs from growing by not absorbing food particles, liquids, or stains.
- **Resistance to staining**: It is stain-resistant, ensuring that the equipment keeps its look even after extended contact to food-related contaminants.
- **Food safety compliance:** 304 stainless steel satisfies or surpasses legal requirements for materials in contact with food, making it safe for use in the food sector.

2) Dimensions of Preheating Boiling Pan

It is important to choose a pan that is appropriately sized for the volume of liquid being boiled. A pan that is too small can cause the liquid to boil over. So, keeping in view appropriate boiling the boiling pan size will be 2ft by 2ft which is enough to boil 5L sugarcane juice.

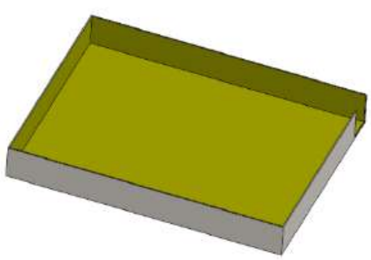


Figure 3.11: Pre Heater Boiling Pan

3.3.4. Specifications of Furnace

1) Materials of Furnace

Furnace will be made up of following different materials:

Fire Bricks

Furnace is made up of specially designed fire bricks due to following reasons

- **High heat tolerance:** Fire bricks are made to endure very high temperatures, which makes them perfect for creating stoves that produce a lot of heat.
- **Good Thermal Insulation:** Fire bricks offer good thermal insulation qualities, which reduce heat loss and increase the stove's energy efficiency.
- **Fire resistance:** Fire bricks offer a safe atmosphere in the fireplace because they are extremely fire resistant and can survive direct exposure to flames without splitting or dissolving.
- **Chemical resistance:** Fire bricks are tolerant to the corrosive effects of different chemicals and gases, assuring both the endurance of a fireplace and their own durability.
- **Low Thermal Conductivity:** Fire bricks do not transfer heat well because of their low thermal conductivity. This characteristic keeps the furnace's inside temperature stable and prevents heat from leaking into the surrounding area.
- **Structural stability:** Fire bricks are durable and structurally solid, able to endure enormous weights as well as the stresses and strains brought on by kiln operation.
- **Simple to install:** Fire bricks are simple to cut, shape and adapt to the unique requirements of the furnace, enabling variation and effective construction.
- **Thermal shock resistance:** Fire bricks have a high thermal shock resistance, which means they can survive rapid temperature fluctuations without cracking, protecting the oven's structural integrity.
- **Non-reactivity:** Firebricks are appropriate for a range of industrial furnaces since they are inert to the majority of substances, including molten metal and slag.
- **Insulation against outside heat:** Firebricks offer a barrier between the hot stove and the environment, lowering the possibility of heat-related damage to adjacent equipment or structures.

Figure 3.12: Fire Bricks

Fire Bricks Binder

Special type of fire bricks binder used for fire bricks due to following reasons:

- **Strengthened bond:** Special binders created especially for fire bricks can strengthen the bond, keeping the bricks securely in place and preventing breaking or moving during high-temperature operation.
- **Improved heat resistance:** Fire brick binders are made to survive extremely high temperatures without degrading or losing their adhesive characteristics, preserving the structural integrity of the fire bricks and the entire building.
- **Reduced shrinkage:** Fire brick binders include properties that reduce shrinkage, reducing the possibility of cavities or gaps between the bricks and promoting a tight and solid binding.
- **Enhanced chemical resistance:** Binders protects fire bricks from chemical deterioration and extend their lifespan by providing enhanced resistance to corrosive chemicals and gases.
- **Customized thermal expansion:** The utilization of fire brick binders permits the customization of thermal expansion characteristics, guaranteeing conformity with the particular fire brick materials and decreasing the likelihood of cracking caused by thermal pressure.

- **Augmented moisture resistance:** Adhesives offer better moisture resistance, diminishing the possibility of water seepage into the fire bricks and conserving their effectiveness at elevated temperatures.
- **Adherence to industrial norms:** Adhesives are formulated to comply with industry norms and regulations for fire bricks, assuring that the final product satisfies the necessary requirements and performance standards.

Bagasse as a fuel

Bagasse is used as a fuel in furnace for boiling of sugarcane juice. Bagasse is used as a fuel due to following reasons:

- **Abundant and sustainable resource:** Bagasse, the fiber leftover after extracting juice from sugarcane, is an abundant and renewable resource that is readily available as a byproduct of the sugar industry. It serves as a sustainable and renewable fuel source for making jaggery, reducing dependence on non-renewable energy sources.
- **Cost-effective:** Utilizing bagasse as a fuel source can be economical, as it is often readily available at sugar mills or sugarcane processing facilities, reducing the need for purchasing or transporting additional fuel.
- **Energy-efficient:** Bagasse has a high calorific value, which means it contains a significant amount of energy. Burning bagasse in the furnace ensures efficient combustion and harnessing of its energy content for the jaggery-making process.
- **Waste utilization:** By using bagasse as a fuel, the sugar industry can effectively utilize the waste generated during sugarcane processing. This practice promotes sustainability by reducing waste disposal and utilizing a resource that would otherwise be discarded.
- **Reduced greenhouse gas emissions:** Bagasse is a carbon-neutral fuel source since the carbon dioxide released during its combustion is offset by the carbon dioxide absorbed by the growing sugarcane. Therefore, using bagasse for fuel contributes to lower greenhouse gas emissions compared to fossil fuel alternatives.
- **Advantages for the local economy:** The utilization of bagasse as a fuel source can have a positive impact on the local economy in sugar-producing regions. This is because it adds value to the sugarcane processing industry and decreases the need to import or buy other kinds of fuel.

- **Decreased reliance on external energy sources:** When bagasse is used as the primary fuel source, jaggery producers can decrease their reliance on external energy sources. This ensures that their energy supply is more dependable and self-sufficient.
- **Promotion of sustainable agricultural practices:** The use of bagasse as a fuel source aligns with sustainable agricultural practices. This is because it closes the loop in the sugarcane industry, promotes efficient use of resources, and decreases the environmental impact of traditional waste disposal methods.
- **Conservation of natural resources:** Bagasse as a fuel source reduces the demand for non-renewable energy sources. This contributes to the conservation of natural resources like fossil fuels.

Air Inlet Window

In furnace the air inlet window is designed for following purpose:

- **Regulation of combustion process:** The aperture for air intake or oxygen provision in a furnace provides precise regulation of the combustion process. By controlling the amount of air entering the furnace, the operator can regulate the oxygen levels to achieve optimal conditions for combustion.
- **Effective fuel utilization:** Appropriate oxygen provision is essential for effective fuel combustion. The aperture for air intake enables the furnace to receive the required amount of oxygen, resulting in more thorough combustion and enhanced fuel utilization.
- **Temperature management:** The presence of an air inlet aperture facilitates temperature management within the furnace. By regulating the oxygen supply, the operator can control the intensity of the combustion, thereby managing the temperature levels required for the specific application.
- **Flame steadiness:** The regulated oxygen supply through the air inlet aperture helps maintain a steady flame inside the furnace. Adequate oxygen ensures the availability of the necessary conditions for a consistent and stable flame, promoting efficient heat transfer.
- **Pollution reduction**: Proper oxygen supply aids in achieving optimal combustion conditions, which can help reduce the production of harmful pollutants such as carbon monoxide (CO) and unburned hydrocarbons. This contributes to improved air quality and reduced environmental impact.

- **Enhanced safety measures:** The existence of an air intake opening ensures sufficient oxygen availability, which hinders the development of risky fuel-saturated surroundings that may cause imperfect combustion or the creation of harmful fumes.
- **Avoiding excessive heat:** By ensuring proper oxygen supply through the air intake window, overindulgence in fuel combustion and furnace overheating is prevented. This safeguards the furnace construction and extends its durability.
- **Augmented process dependability:** The controlled oxygen delivery via the air inlet window maintains stable combustion settings, leading to better process dependability, uniform heat distribution, and trustworthy furnace performance.

Exhaust Gas Hole

Exhaust hole in furnace is made on top corner for following purposes.

- **Elimination of combustion byproducts:** The outlet hole of furnace exhaust gases facilitates the efficient elimination of combustion byproducts, including carbon dioxide, water vapor, sulfur dioxide, and other gases produced during the combustion process. This promotes a safe and hygienic working environment. ·
- **Prevention of hazardous gas buildup:** Adequate ventilation of exhaust gases prevents the accumulation of potentially harmful gases within the furnace. By providing a channel for these gases, it ensures their safe expulsion from the furnace, thus reducing the risk of harm to equipment and operators. ·
- **Heat dissipation:** The exhaust gases outlet hole plays an important role in dissipating excess heat generated during combustion. It helps maintain the appropriate temperature levels within the furnace, thus preventing overheating and possible damage to the furnace's structure and surrounding equipment. ·
- **Reduction of air contamination:** By directing the combustion byproducts outside the furnace, the exhaust gases outlet hole significantly minimizes air pollution. It ensures the safe venting of released gases, thus preventing local air quality degradation. ·
- **Enhanced combustion efficiency:** Proper exhaust gas ventilation facilitates improved combustion efficiency by maintaining optimal oxygen levels within the furnace. It prevents the

accumulation of gases that could hinder combustion and ensures a constant supply of fresh air for combustion. ·

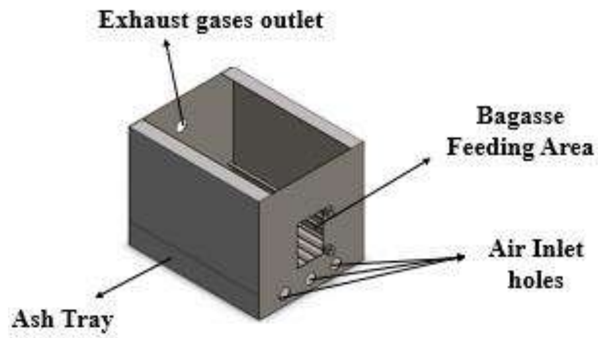
- **Elimination of unpleasant odors and fumes**: Furnace processes may generate unpleasant or harmful odors and fumes. The exhaust gases outlet hole promotes the elimination of these odors and fumes, thus contributing to a more comfortable and healthier working environment.
- **Overall safety:** The presence of an exhaust gases outlet hole is vital to the overall safety of the furnace and its surrounding environment. It prevents the accumulation of toxic or flammable gases, reduces the risk of overheating, and promotes safe and controlled operation.

Ash Collecting Tray

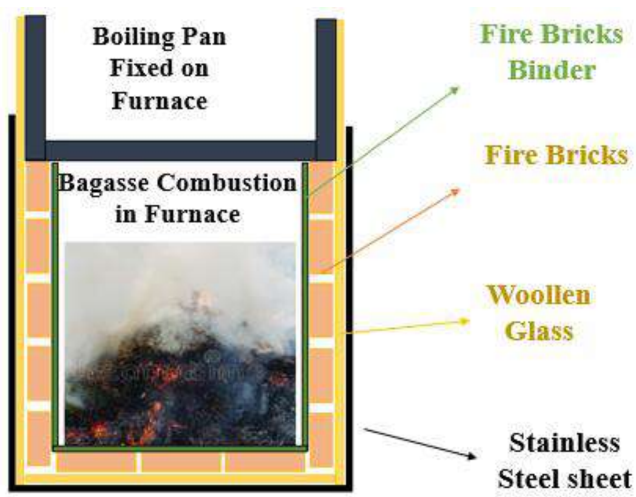
Asha collecting tray is placed in furnace for following reasons:

- **Ash elimination:** The ash collection tray in a furnace allows for convenient and efficient elimination of the ash produced during the combustion process. It prevents the accumulation of ash, which can disrupt proper furnace operation and decrease its efficiency. ·
- **Upkeep and Sanitation**: The ash collection tray assists in maintaining a hygienic and organized furnace atmosphere. By gathering the ash in one location, it prevents the ash from spreading or entering other furnace components, making upkeep and sanitation simpler. ·
- **Fire Prevention:** The presence of an ash collection tray reduces the chance of fire. Ash is a combustible material, and if not managed correctly, it can ignite and create a fire hazard. The tray contains the ash, preventing it from coming into contact with flammable materials or causing accidental fires. ·
- **Enhanced Efficiency:** Regular elimination of ash from the furnace through the ash collection tray helps maintain optimal furnace efficiency. Accumulated ash acts as an insulator, reducing heat transfer and hindering combustion. By keeping the furnace free from ash buildup, it can operate at its highest efficiency levels. ·
- **Extended Equipment Life:** Ash buildup can cause corrosion and deterioration of furnace components. The ash collection tray prevents the ash from touching critical furnace parts, thus reducing the risk of damage and extending the equipment's lifespan**.** ·
- **Environmental Considerations:** Collecting ash in a designated tray helps contain it, preventing it from dispersing into the surrounding environment. This minimizes the impact on air quality and reduces the potential for ash pollution. ·

- **Simpler Disposal:** Having an ash collection tray facilitates ash disposal. Once the tray is full, it can be easily removed and emptied into appropriate waste disposal systems, ensuring proper handling and disposal of the ash material.



(a)



(b)

Figure 3.13. Furnace CAD and General Design

3.3.5. Specifications of ID Fan

Purpose of ID Fan

An Induced Draft (ID) fan is a mechanical device that is commonly used in industrial processes for suction of exhaust gases in a system. The main purpose of an ID fan is to draw flue gases and other hot air streams from the combustion chamber of furnace and push them through the flue gas pathway.

Use of ID Fan in our case

The purpose of ID fan is to suck exhaust gas. One ID fan will be installed to suck exhaust gases from furnace. 2nd ID fan will be installed at the end of preheating exhaust gas chamber to suck exhaust gases from preheating chamber and will be released in atmosphere

3.3.6. Specifications of Insulating Material

Specification Woolen Glass

Woolen glass insulation, also known as fiberglass insulation, is a type of thermal insulation made from fine fibers of glass

Purpose of Woolen Glass

Woolen glass is chosen for the purpose of insulation in our system where needed due to following properties.

1) Very low thermal conductivity (0.034 W/m K).
2) Moisture resistant.
3) Fire resistant.
4) Lightweight.
5) Withstand Temperature (Up to 1450^{o}C).
6) Provides corrosion protection.

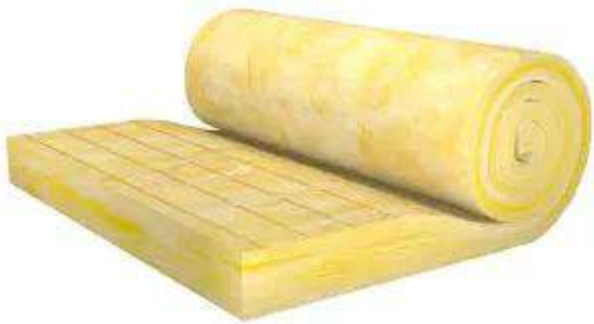


Figure 3.14: Glass Wool

3.4. Overall CAD design

Following is the overall CAD Design that we designed on Solidworks.

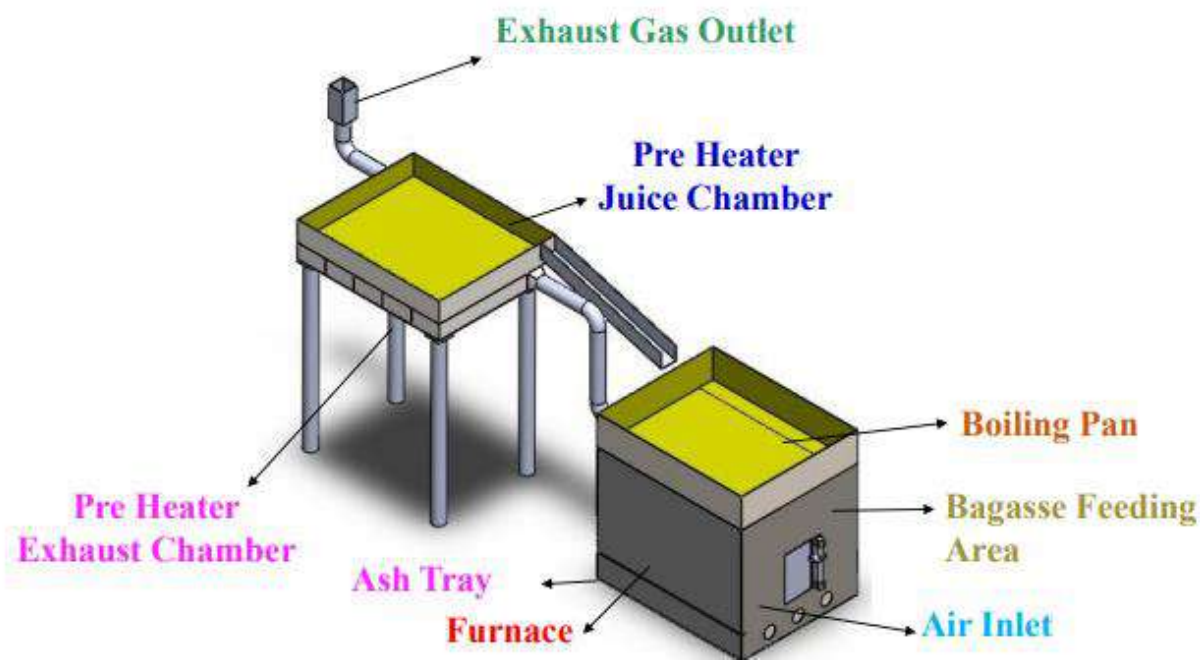


Figure 3.15: Overall CAD Design of Brown Sugar Making Machine

Chapter 4

TOOLS AND TECHNIQUES

4.1. SolidWorks

The project's model was crafted using SolidWorks, a powerful design software. This tool enabled the creation of a detailed and accurate representation of the envisioned product. Through SolidWorks, intricate aspects of the design were meticulously refined, ensuring precise measurements, intricate shapes, and seamless assembly. The software's user-friendly interface facilitated the manipulation of various components, allowing for easy adjustments and enhancements to achieve the desired functionality and aesthetics. The utilization of SolidWorks significantly expedited the design process, resulting in a visually appealing and intricately structured model that forms the foundation for the project's realization.

4.2. ANSYS

For the project's simulation phase, ANSYS software proved invaluable. ANSYS facilitated a comprehensive analysis of the design's behavior and performance under different conditions. Through intricate simulations, the software allowed for the evaluation of stress distribution, thermal behavior, and fluid dynamics, providing insights into potential strengths and weaknesses. ANSYS enabled the exploration of real-world scenarios, aiding in the identification of potential issues and optimization opportunities prior to physical prototyping. By subjecting the design to virtual testing, ANSYS played a pivotal role in ensuring the project's structural integrity and functionality, contributing to informed decision-making and ultimately enhancing the project's overall success.The ANSYS simulation focused on a crucial aspect of the project: the temperature analysis of the preheated juice within the preheater boiling chamber. Through meticulous simulation, ANSYS provided a comprehensive view of how heat is transferred and absorbed by the juice as it traverses the preheater chamber. This analysis involved a detailed exploration of temperature gradients, ensuring that the juice attains the desired level of preheating while maintaining optimal thermal conditions. By virtually replicating the heat exchange process, ANSYS revealed invaluable insights into the distribution of temperatures, thereby aiding in fine-tuning the preheater's design for enhanced efficiency and precision in the treatment of the juice.

4.3. Manufacturing Techniques

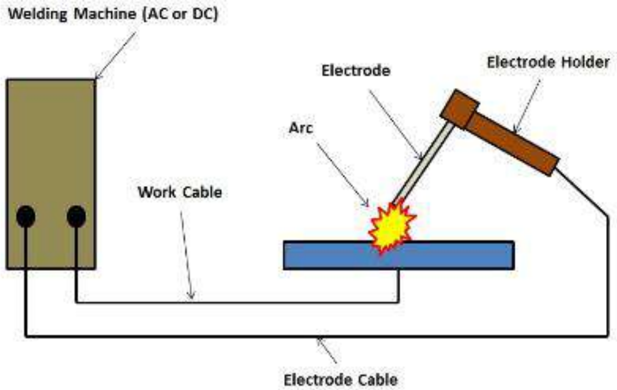
Following techniques are used for the manufacturing purpose of this project

4.3.1. Arc Welding

Different types of components are fabricated using welding techniques. For fabrication of different components like furnace stand, furnace gate, furnace window, ash tray, preheater formation arc welding is done.

(a)

Arc welding is a welding process that uses an electric arc to join metal pieces together. It involves creating an electrical circuit between an electrode (a metal wire or rod) and the workpiece, generating intense heat that melts the metal and forms a weld joint.



(b)

Figure 4.1. Arc Welding

(a) Arc Welding, (b) Arc Welding Circuit Diagram

4.3.2. Argon Welding

Argon welding is done to fabricate boiling pan made up of stainless steel. It is done because it provides protection against corrosion as compared to argon welding.

Argon welding, also known as gas tungsten arc welding (GTAW), is a precise and versatile welding process used to join metals. It employs a non-consumable tungsten electrode to produce the weld, with an inert gas, typically argon, shielding the weld area from atmospheric contamination. The electric arc generates intense heat, melting the metal pieces, and the argon gas forms a protective environment preventing oxidation and ensuring a clean weld. This method is widely used in industries like aerospace, automotive, and electronics due to its ability to create high-quality, defect-free welds on various metals, including aluminum, stainless steel, and copper alloys. The process requires skill and finesse, making it suitable for delicate and critical applications

Figure 4.2. Argon Welding

4.3.3. Laser Cutting

Laser cutting is used for the cutting of pre heating boiling and exhaust chamber metal sheet cutting. Also it is used for the cutting of stainless steel sheet of boiling pan. This technique is used for precision and complex design cutting.

Laser cutting is a precise and efficient industrial process used to cut through various materials, such as metals, plastics, and wood. It utilizes a high-powered laser beam focused on the material's surface, causing localized heating and vaporization, which creates a narrow, clean cut. The laser beam's intensity can be controlled, allowing for intricate and complex designs with minimal material wastage. This method is popular in industries like manufacturing, automotive, and electronics due to its speed, accuracy, and ability to cut a wide range of materials. Laser cutting offers significant advantages over traditional cutting methods, making it an essential technology for modern production processes

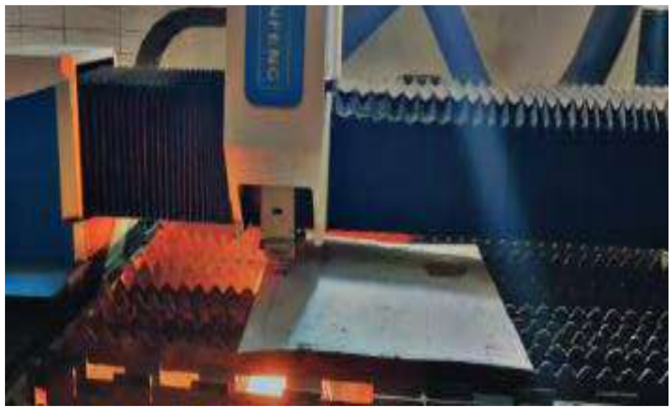


Figure 4.3. Laser Cutting

4.3.4. Bending

Bending is used for bending metal sheets of pre heater boiling and exhaust chamber. Also it is used for boiling of boiling pan. It is used where high precision requirement needed.

Bending metal sheets using a bending machine is a fundamental process in the field of sheet metal fabrication. The process begins with carefully placing the metal sheet on the bending machine's bed or lower die, ensuring proper alignment. The appropriate upper die or punch is selected, considering factors such as the required bend angle and material thickness. The bending machine's controls or computer numerical control (CNC) system are then set up to specify the desired bend angle, length, and other necessary parameters.

During the bending process, the bending machine's ram applies force to the metal sheet, pressing it against the stationary lower die and forming the desired bend. Modern bending machines offer precision and repeatability, enabling consistent results even for high-volume production. Some machines may also feature a back gauge to help position the sheet accurately for multiple bends or complex shapes. After bending, the formed part is inspected to ensure it meets the required specifications and tolerances.

Figure 4.4. Bending

4.3.5. Grinding

Grinding is used for grinding of every parts to removes extra material for better finishing.

Grinding is a material removal process used in various industries to achieve precise and smooth surface finishes on workpieces. In this process, an abrasive wheel rotates at high speed and comes into contact with the workpiece, removing unwanted material in the form of small chips. The grinding wheel's abrasive particles can be made of various materials, such as aluminum oxide, silicon carbide, or diamond, depending on the specific application and material being worked on. Grinding is commonly used for finishing tasks, such as sharpening tools, removing burrs from metal parts, and achieving tight tolerances on machined components.

Figure 4.5. Grinding

4.3.6. Cutting

Cutting process is used for cutting of rectangular pipes and metal sheets.

Cutting wheels, also known as abrasive wheels or cutoff wheels, are important tools used for precise and efficient cutting in various industries. These wheels are made of abrasive materials, such as aluminum oxide or silicon carbide, bonded together to form a strong and durable disc. When attached to a handheld angle grinder or stationary machine, the cutting wheel spins at high speed, allowing it to slice through different materials, including metal, steel, stainless steel, and masonry. During the cutting process, the abrasive grains on the wheel's edge wear down the workpiece surface, creating small chips that facilitate smooth and accurate cuts. Cutting wheels are available in different diameters and thicknesses to suit various cutting tasks and material types. They are particularly popular in metalworking, fabrication, construction, and maintenance jobs due to their versatility and ease of use. However, safety precautions, such as wearing proper personal protective equipment and observing recommended operating speeds, must be followed to prevent accidents and ensure optimal cutting performance. Regular inspection and replacement of worn-out cutting wheels are essential to maintain cutting efficiency and minimize the risk of accidents during cutting operations

Figure 4.6. Cutting

4.4. Specifications of Fabricated Parts

4.4.1. Furnace:

It is made up of fire bricks and clay as a binder. The total height of the furnace is about 34 inches from the ground and has a full metal stand with metal tires having high load bearing capacity. The total base surface area of furnace is about 2x2 feet squared and a cavity of 18x18 inches squared and height of 22 inches. The walls are coated with clay from the inside and cement from the outside to provide batter insulation. The total weight of the furnace is about 230 to 300 kg and it has the following components

- A drawer for carrying the fuel at the time of burning and ashes after the burning that can be removed after the burning process by removing the drawer.
- A window for the entrance of air that is required for combustion of fuel.
- A gate to insert the fuel into the furnace during combustion to maintain the temperature inside the furnace.
- A clamping system that is responsible for transforming the exhaust gases to the heat exchanger.

Figure 4.7. Fabricated Furnace

4.4.2. Boiling Pan:

Boiling pan that is the main pan in which the brown sugar is made at the end of the process. It is made up of stainless steel which is non-magnetized (food grade) it has a base surface area of about 17x17 inches squared and a depth of 4 inches the outward edges are extended to provide the sealing for the leaking gas from the furnace and support to the pan to fix above the furnace.

Figure 4.8. Fabricated Boiling Pan

4.4.3. Pre heater exhaust chamber:

The exhaust chamber is made up of iron as it does not have to carry any food material. It is covered with a black corrosion resistant spray. It contains one entrance and one exit for exhaust gases and has multiple fins that does not only increase the heat transfer rate but also provides a passage for exhaust gases that increase the time of stay of exhaust gases in the heat exchanger it has extended edges which provides the location for bolts to form a tight grip between the pre heating pan and exhaust chamber. A frame of iron rods is welded below the exhaust chamber which provides support and a space for insulation for exhaust chamber.

Figure 4.9 Fabricated Pre Heated Exhaust Chamber

4.4.4. Pre heater pan:

It is made up of non-magnetized food grade stainless steel with the same cross section as of exhaust chamber but an increase of 1.5 inches in height. It has the fins of same dimensions and location as in exhaust chamber for a nearly perfect sitting of pan on exhaust chamber to avoid leaking of exhaust gases. It has an extended pipe in the wall facing furnace to transfer pre heated juice to the main boiling pan. It has a frame attached on the sides which provides it support and the location for bolts to fix it on the exhaust chamber.

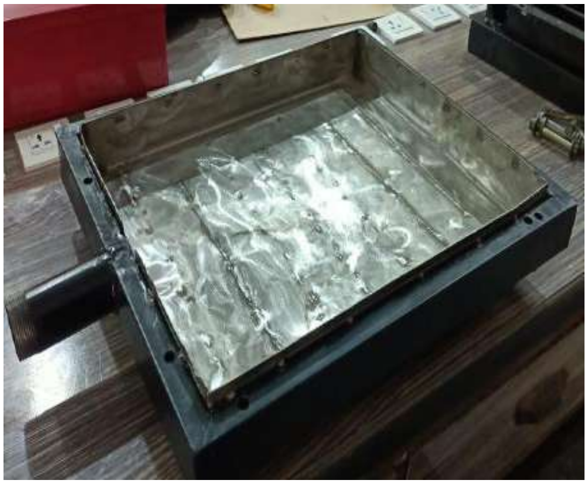


Figure 4.10. Fabricated Pre Heater pan

4.4.5. Exhaust pipe:

It is the pipe that connects the furnace to the heat exchanger. Its function is to carry the exhaust gases from the furnace to the heat exchanger. And for this purpose it is made up of stainless steel that can carry high temperature and pressure gasses. It has the internal diameter of 4 inches so that exhaust gases can enter into it easily and this ultimately help us in the reduction of suction power. A reducer is attached at the end of pipe to connect it easily with preheater boiling chamber. A coupling was attached in furnace to connect it easily with furnace side for transferring exhaust gases from furnace to pre heater.

Figure 4.11. Exhaust Gas Pip

4.4.6. Juice Transferring Tray

Juice transferring tray is used for transferring pre heating juice from pre heater boiling chamber to main boiling pan. It is made up of 304 stainless steel so its material does not reacts with juice.

Figure 4.12. Fabricated Juice Transferring Tray

4.4.7. Woolen Glass

Woolen glass is used for the purpose of insulation to reduce heat losses in furnace, exhaust gas pipe and pre heater. It is wrap around these parts to reduce heat losses and make the whole process efficient. Woolen glass is chosen for the purpose of insulation in our system where needed due to following properties;

- Very low thermal conductivity
- Moisture resistant
- Fire resistant
- Lightweight

Figure 4.13. Woolen Glass Insulation

4.4.8. Supporting Stand

Supporting stand is used to support pre heater. It is made up of rectangular iron pipes.

Figure 4.14. Fabricated Supporting Stand

4.5. Overall Fabricated Model

Overall fabricated model is shown in following figure. It consists of following main components;

- Furnace.
- Pre Heater
- ID Fan
- Exhaust Gas Pipe

Figure 4.15. Overall Fabricated Project

One beneficial thing about this project is that it can be disassemble and can be move anywhere.

4.6. Testing of Fabricated Model

After the fabrication of model testing is performed to get the experimental results. Following is the step wise process for the testing of practical model;

4.6.1. Steps for Testing of Fabricated Model

Following steps are followed to make brown sugar using fabricated model;

- **Placing of boiling pan on furnace**

First of all, we place the boiling pan on furnace.

Figure 4.16. Placing Boiling Pan on Furnace

- **Pouring of sugarcane juice**

In this step juice is poured in boiling pan for purpose of boiling. 5L of sugarcane juice is poured in boiling pan container.

Figure 4.17. Pouring Sugarcane Juice in Boiling Pan

- **Feeding of Bagasse**

In this step bagasse is feeded in furnace manually.

Figure 4.18. Feeding of Bagasse in Furnace

- **Burning of bagasse**

After bagasse is feeded manually in furnace it starts burning inside furnace.

Figure 4.19. Burning of Bagasse in Furnace

- **Stirring of juice**

In this process stirring of juice takes place. Using a long-handled stirring rod, slowly and consistently stir the juice to promote even heating and gradual concentration.

Figure 4.20. Stirring of Juice

- **Boiling of Sugarcane Juice**

The next step in the experiment involved boiling the sugarcane juice. The juice was transferred into a large pot and placed over medium heat. As the temperature rose, the liquid began to simmer and gradually reduce in volume. Careful attention was paid to prevent any scorching, and the juice was boiled until it thickened and transformed into a rich brown color, indicating the formation of brown sugar.

Figure 4.21. Boiling of Juice

- **Boiling Juice Temperature Measuring**

A temperature measuring sensor is installed to regularly measured the temperature of boiling juice.

Figure 4.22. Boiling Juice Temperature Measurement

- **Preheating Juice Temperature Measuring**

One temperature sensor is also installed to measure the temperature of pre heated juice. Temperature of 68^0C is achieved for preheated juice.

Figure 4.23. Preheating Juice Temperature Measuring

- **Transferring of Pre Heated Juice to Boiling Pan**

When first batch of making brown sugar is completed by using without pre heated juice the juice from pre heated boiling chamber is transferred to main boiling pan for second batch of brown sugar making.

Figure 4.24. Transferring of Pre Heated Juice to Boiling Pan

- **Exhaust Gas Temperature Measuring**

A thermocouple is installed to measure temperature of exhaust gas and a control unit is used to display that temperature

Figure 4.25. Exhaust Gas Temperature Measuring

- **Pouring of Concentrated Juice**

When desired amount of water content is evaporated from sugarcane juice during boiling juice become concentrated and it is then poured in a tray to become cool at room temperature.

Figure 4.26. Pouring of Concentrated Juice

- **Final Product Brown Sugar**

When concentrated juice become cool at room temperature brown sugar formation is occurs.

Figure 4.27. Brown Sugar

4.7. Summary

In this section, the tools and methods for the project are discussed. SolidWorks was used for designing, while ANSYS simulated its performance. The report explains the created parts, their functions, and the fabrication process. It outlines the steps taken to test the design and ensure its practicality. The successful completion of the project's goals is highlighted through these applied techniques and processes.

Chapter 5

RESULTS AND DISCUSSIONS

5.1. Simulation Results

Simulation result shows that juice in pre heated container reaches upto temperature of 72^0C.

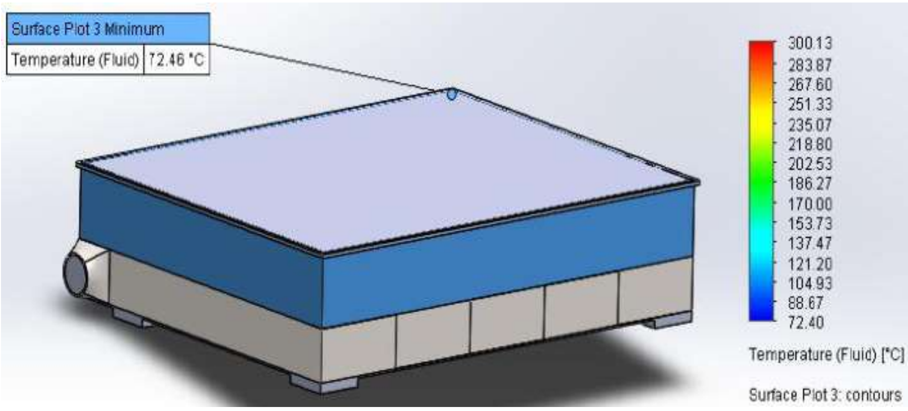


Figure 5.1. Simulation Results of Preheating Juice Temperature

5.2. Experimental Results

5.3. Technical Aspects of Fabricated Model

Following are the technical aspects of this project;

- Without Pre heating thermal efiicency of 19% achieved
- With pre heating thermal efficiency of 36.8% achieved
- 22% efficiency increases as compared to traditional method
- Without pre heating 4kg of bagasse consumed to produce 1.8kg brown sugar
- With Pre heating 2.05kg of bagasse consumed to produce 1.75kg brown sugar
- Consumption of fuel (bagasse) reduced upto 1.90kg for same amount brown sugar production
- Furnace (Temperature up to 700ºC raised)
- Thermally insulated Stainless Steel Pipe (Withstand temperature of flue gases up to 310ºC)
- Preheater (Juice absorbed 68ºC temperature in preheating
- Glass wool insulation of 15mm wrap around furnace, preheater and pipe.

5.4. Comparison Between Simulation and Experimental Results

Following table shows the comparison between experimental and simulation results.

Experimental vs Simulation results Table		
Preheated Juice Temperature in ºC (Simulation)	**Preheated Juice Temperature in ºC (Experimental)**	**%Error**
72	68	5.12

Table 5.1: Experimental vs Simulation Results Table

Following table shows thermal efiicency comparison.

Thermal Efficiency Comparison Table		
Method	**Thermal Efficiency % (Traditional)**	**% Increase in Thermal Efficiency as Compared to Traditional Method**
Traditional	14.4	0
Without utilizing Preheated Juice	18.8	4.4
By utilizing Preheated Juice)	36.7	22.3

Table 5.2: Thermal Efficiency Comparison Table

5.5. Causes of Errors

About 5.12% differences between simulation and real tests are due to a few reasons. The heat might not be applied correctly, and insulation might not be enough, causing heat to escape. The computer model can't perfectly copy real situations, which leads to temperature predictions being slightly off. Insufficient insulation causes heat loss, affecting the accuracy of real tests. To fix this, better heating methods and stronger insulation are needed.

Chapter 6

CONCLUSION AND FUTURE RECOMMENDATIONS

6.1. Conclusion

By designing and fabricating a brown sugar making machine with a focus on optimizing thermal efficiency, we have taken a significant step towards empowering farmers and advancing sustainable agricultural practices. Our primary objective of enabling farmers to transport brown sugar instead of raw sugarcane has been realized through the integration of a novel concept: harnessing flue gases from bagasse combustion to pre-heat sugarcane juice. Despite a slight disparity between simulation and experimental results, the achievement of pre-heating juice temperatures of 72°C and 68°C respectively highlights the successful application of this concept.

Comparative analysis between our approach and the traditional method underscores the tangible benefits. The transition from a mere 19% thermal efficiency without pre-heating to a substantial 36% efficiency with pre-heating demonstrates the remarkable potential of our innovation. This efficiency improvement translates to a significant reduction in bagasse consumption from 4kg to 2.10kg for the same output of brown sugar. The experimental setup, yielding a pre-heating temperature of 67°C, underscores the practical viability of our approach. The resultant 22% increase in thermal efficiency compared to traditional methods further accentuates the positive impact of our intervention.

In essence, our project presents a promising blueprint for a more sustainable and economically robust sugar production paradigm. By enhancing farmer empowerment and offering a greener alternative, we believe our innovative brown sugar making machine can contribute to the holistic development of the agricultural sector, fostering both economic growth and environmental consciousness. This work serves as an invitation to further exploration and collaboration in realizing the full potential of this transformative approach to sugar production.

This project doesn't just change how we make sugar; it empowers farmers and shows how smart ideas can make farming better for everyone. It's a small step towards a stronger farming economy and a greener environment

6.2. Future Recommendations

Following are the future recommendations of this project;

- **Optimization and Scaling:** Further optimize the design and functionality of the brown sugar making machine for larger scale production, ensuring its efficiency and viability in real-world scenarios.
- **Integration with Agricultural Practices:** Explore seamless integration of the machine into existing agricultural setups, promoting a holistic approach to sugar production within local farming communities.
- **Energy Recovery Systems:** Investigate the potential for harnessing additional sources of waste heat or energy within the sugar production process to further enhance thermal efficiency and resource utilization.
- **Collaborative Research:** Foster collaboration between academia, industry, and agricultural stakeholders to refine and adapt the technology, while continuously improving its economic and environmental impact.
- **Market Accessibility:** Focus on making the brown sugar making machine accessible and affordable to small-scale farmers, ensuring widespread adoption and maximizing its benefits across diverse agricultural landscapes.
- **Technological Advancements:** Keep pace with emerging technologies and innovations that could further enhance the efficiency, sustainability, and usability of the machine, enabling continuous improvement and adaptation.
- **Sustainability Metrics:** Develop a comprehensive set of sustainability metrics to measure the socio-economic and environmental impact of the brown sugar making machine, providing a clear basis for its contribution to sustainable agriculture.
- **Knowledge Sharing:** Establish platforms for knowledge sharing and capacity building, enabling farmers to learn about and adopt the technology, while also promoting the exchange of best practices and lessons learned.

- **Policy Advocacy:** Engage with policymakers and relevant governmental bodies to advocate for incentives and support mechanisms that encourage the adoption of innovative technologies like the brown sugar making machine within the agricultural sector.
- **Diversification of Use:** Explore opportunities to diversify the application of the machine's technology, potentially extending its benefits to other areas of food processing and production beyond sugar.

6.3. Areas of Improvement

Following are the areas of improvement in light of this project;

- **Temperature Consistency:** Enhance the consistency between simulation and experimental pre-heating temperatures to ensure accurate and reliable results.
- **Energy Efficiency:** Investigate methods to further optimize the utilization of flue gases and increase energy transfer efficiency during the pre-heating process.
- **Material Selection:** Explore alternative materials for construction that may offer improved durability, heat resistance, and cost-effectiveness for the brown sugar making machine.
- **Scaling Challenges:** Address potential challenges and modifications required for scaling up the machine's production to accommodate larger batches of brown sugar.
- **Process Integration:** Enhance the integration of the machine within existing sugar production workflows, considering factors such as maintenance, cleaning, and ease of operation.
- **Resource Recovery:** Explore opportunities for recovering and repurposing byproducts generated during the brown sugar production process to minimize waste and maximize resource utilization.
- **Automation and Control:** Develop advanced automation and control systems to optimize the entire sugar production process, ensuring consistent quality and reducing the need for manual intervention.
- **User-Friendly Interface:** Design an intuitive user interface and provide comprehensive training to farmers for efficient operation and maintenance of the machine.

- **Environmental Impact:** Conduct a thorough life cycle assessment to quantify and minimize the machine's overall environmental impact, including energy consumption, emissions, and waste generation.
- **Cost Reduction:** Continuously seek cost-effective solutions for both the initial setup and ongoing operation of the brown sugar making machine to make it accessible to a wider range of farmers.
- **Feedback Loop:** Establish mechanisms for gathering feedback from farmers and industry stakeholders to continuously improve the machine's design and functionality based on real-world usage.
- **Regulatory Compliance:** Ensure that the brown sugar making machine meets all relevant safety and regulatory standards, and work towards obtaining necessary certifications for widespread adoption.
- **Community Engagement:** Strengthen engagement with local farming communities to better understand their needs and preferences, and tailor the machine's features accordingly.
- **Performance Metrics:** Develop a comprehensive set of performance metrics to accurately assess the impact and benefits of the brown sugar making machine on farmer income, sugar production efficiency, and environmental sustainability.

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Design & Model Fabrication of Brown Sugar Making Machine from Sugarcane Juice for Small Scale Farming

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