PERFORMANCE EVALUATION OF IISR THREE PAN FURNACE FOR JAGGERY MAKING

M.Tech. (Agril. Engg.) Thesis

by

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CERTIFICATE – I

This is to certify that the thesis entitled **"Performance evaluation of IISR three pan furnace for jaggery making"** submitted in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), is a record of the bonafide research work carried out by **Suraj Kumar** under my/our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

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This is to certify that the thesis entitled "**Performance evaluation of IISR three pan furnace for jaggery making**" submitted by **Suraj Kumar** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** in the Department of **Agricultural Processing and Food Engineering** has been approved by the external evaluator and Student's Advisory Committee after oral examination, under the chairmanship of Head of the Department/Dean (in case of out campii).

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LIST OF NOTATIONS/SYMBOLS

Symbols	Description
B	Weight of bagasse consumed
°C.	Degree Celsius
$C_{bagasse}$	Calorific value of bagasse
Cp_{juic}	Specific heat of juice,
Fig	Figure
h	Latent heat of vaporization of water
kJ	Kilo joule
K	Calories
Kg	Kilo Gram
mm	Millimeter
$T_{initial}$	Initial room temperature of furnace
$Q_{evaporation}$	Total heat utilized for heating the juice
Q_{input}	Heat energy input per batch
$\eta_{thermal}$	Thermal efficiency
W_j	Weight of sugarcane juice per batch,
$W_{bagasse}$	Weight of bagasse required per batch
W_{jag}	Weight of jaggery produced per batch
W_{scum}	Weight of scum removed per batch
W_{water}	Weight of water evaporated per batch.
W_{juice}	Weight of juice
%	Percentage
et al.	And other
i.e	That is

LIST OF ABBREVIATIONS

Abbreviations	Full forms
C.G.	Chhattisgarh
Engg.	Engineering
Etc	Etcetera
FAE	Faculty of Agricultural Engineering
IGKV	Indira Gandhi Krishi Vishwavidyalaya
Min	Minute
M.Tech.	Master of Technology
TSS	Total soluble solid

THESIS ABSTRACT

Title of the Thesis	:	Performance Evaluation of IISR Three Pan Furnace for Jaggery Making
Full Name of the Student	:	Suraj Kumar
Major Subject	:	Agricultural Processing and Food Engineering
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Degree to be Awarded	:	Master of Technology in Agricultural Engineering

Signature of the Student

Signature of Co-Major Advisor

Signature of Major Advisor

Date: 12-04-2021

Signature of Head of the Department

ABSTRACT

The sugarcane is used for the preparation of jaggery. The production of jaggery is the one of the most traditional process and generally produced in cottage industries. This cottage industry provides jobs to the local people of rural areas as well as urban areas. Also, the production of jaggery is the best entrepreneurship

well as urban areas. Also, the production of jaggery is the best entrepreneurship opportunity for the people. The production of jaggery requires best sugarcane variety which having more sucrose percentage about 20°Brix. The variety of the sugarcane also affects the production of jaggery because the different sugarcane variety has different sucrose percentage. If the availability of sucrose percentage in sugarcane juice is more, then the production of jaggery will be more. The traditional furnace is used for the preparation of jaggery. There are many type of furnace used for the jaggery preparation such as single, double, triple and four pan furnace. The bagasse is used as a fuel for heating the juice on the furnace. Jaggery is produced by the boiling of sugarcane juice till the desire consistency (striking point temperature). Then, it removed for cooling and shaping. ICAR-Indian Institute of sugarcane research has developed new improved three pan furnace for jaggery preparation to reduces more bagasse consumption, more jaggery preparation time and heat losses so that increases the heat utilization efficiency of the furnace. The purpose of this study was to evaluate the performance of new improved furnace on the basis of total consumption of bagasse, total time consumption, water evaporation rate during the jaggery preparation. The requirement of bagasse for 1 kg jaggery production was obtained as 2.42 kg bagasse /kg jaggery. The analysis of the flue gas was also important to check the proper combustion of fuel inside the combustion chamber therefore the flue gas contains was analyzed. During the analysis of flue gas it was found that the amount of carbon dioxide percentage (CO_2%) which escapes from chimney was more as compared carbon monoxide percentage (CO%) and oxygen (O_2). This indication resulted the better combustion of fuel into the combustion chamber during jaggery preparation. The total consumption of time and overall water evaporation rate of the furnace was calculated as 1.81 kg/ kg bagasse, 2 h 22 minutes. The overall thermal efficiency for preparation of jaggery was obtained 28.82% of the furnace.

शोध सारांश

शोध का शीर्षक	:	गुड़ बनाने के लिए आईआईएसआर तीन पैन वाले भट्टी के प्रदर्शन का मूल्यांकन करना
छात्र का पूरा नाम	:	सूरज कुमार
प्रमुख विषय	:	कृषि प्रसंस्करण और खाद्य अभियांत्रिकी
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सह प्रमुख सलाहकार का नाम और पता	:	डॉ. दिलीप कुमार प्रधान वैज्ञानिक, (पीएचटी), कृषि अभियांत्रिकी विभाग आईसीएआर–आईआईएसआर, लखनऊ (उ.प्र.)
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छात्र का हस्ताक्षर

सह प्रमुख सलाहकार का हस्ताक्षर

प्रमुख सलाहकार का हस्ताक्षर

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विभाग के प्रमुख का हस्ताक्षर

सारांश

गन्ने का उपयोग, गुड़ बनने के लिए किया जाता है। गुड़ का उत्पादन पारंपरिक प्रक्रियो में से एक है जो आम तौर पर कुटीर उद्योगों में उत्पादित होता है। यह कुटीर उद्योग ग्रामीण लोगों के साथ–साथ शहरी क्षेत्रों में भी रोजगार प्रदान करता है। साथ ही, गुड़ का उत्पादन लोगों के लिए सबसे

अच्छा उद्यमशीलता का अवसर भी है। गुड़ के उत्पादन के लिए सर्वोत्तम गन्ने की किस्म की आवश्यकता होती है, जिसमें कम से कम 19–20° ब्रिक्स सुक्रोज हो। गन्ने की किस्म भी गुड़ के उत्पादन को प्रभावित करती है क्योंकि अलग–अलग गन्ने की किस्म में अलग–अलग सूक्रोज प्रतिशत होती है। यदि सुक्रोज प्रतिशत की उपलब्धता गन्ने में अधिक है तो गुड़ के उत्पादन की संभावना अधिक होगी। पारंपरिक भट्टी का उपयोग गुड़ बनाने के लिए किया जाता है, जो आम तौर पर ग्रामीण क्षेत्रों में आग की ईंटों से बनाया जाता है। गुड़ की तैयारी के लिए कई प्रकार की भट्टी का उपयोग किया जाता है जैसे सिंगल, डबल, ट्रिपल और फोर पैन भट्टी। कोल्हू का उपयोग गन्ने की पेराई के लिए गया, जिसमें रस निकालने की दक्षता 60 प्रतिशत थी। गन्ने को कुचलकर गन्ने का रस और खोई प्राप्त किया जाता है। खोई का उपयोग, रस को गर्म करने के लिए ईंधन के रूप में किया गया। गुड़ बनने के लिये, गन्ने के रस को स्ट्राइकिंग पॉइंट टेम्परेचर (116–118°C) तक उबाला गया । फिर इसे ठंडा करने और आकार देने के लिए निकला गया। भारतीय गन्ना अनुसंधान ने गुड़ की तैयारी के लिए नए बेहतर तीन पैन भट्टी विकसित किया हैं ताकि भट्टी की उष्मा दक्षता बढ़ जाए। इस अध्ययन का उद्देश्य भट्टी के प्रदर्शन का मुल्यांकन, खोई की कुल खपत, कुल समय की खपत तथा जल के वाष्पीकरण दर के आधार पर करना था। इस भट्टी में 1 किग्रा गुड़ उत्पादन के लिए खोई की आवश्यकता 2.42 किग्रा थी। फ्लू गैस का विश्लेषण भी दहन कक्ष के अंदर, ईंधन के उचित दहन की जांच करने के लिए किया गया। फ्ल्यू गैस के विश्लेषण के दौरान यह पाया गया कि कार्बन डाइऑक्साइड प्रतिशत, कार्बन मोनोऑक्साइड प्रतिशत और ऑक्सीजन की तुलना में अधिक था। इस संकेत के परिणामस्वरूप गुड़ की तैयारी के दौरान दहन कक्ष में ईंधन का बेहतर दहन दिखाया गया। समय की कुल खपत 2 घंटा 22 मिनट थी तथा भट्टी के जल वाष्पीकरण की दर 1.81 किग्रा प्रति किग्रा खोई के रूप में की गई। इस भट्टी की उष्मा दक्षता 28.82 प्रतिशत प्राप्त की गई।

CHAPTER – I
INTRODUCTION

Sugarcane (*Saccharum officinarum*) is a major cash crop in India belonging to the family *Gramineae*. It is usually used to produce sweeteners like sugar, jaggery (*gur*), and *Khandsari*. After Brazil, India is the second largest producer of sugarcane in the world. In India namely, Utter Pradesh and Maharastra is the two largest sugar producing states. The yield of sugarcane in the financial year 2019 was estimated approximately 78 thousand kilograms per hectare across India and approximately 53% used for the production of refine sugar, 36% used as jaggery and *khandsari* production, 3% consumed as cane juice and 8% as seed cane (Statista, 2020).

The jaggery is a traditional, unrefined, natural sugar that is produced by evaporating water from sugarcane juice in steel or iron pans placed over pit furnaces. It is a concentrated product of cane juice with the molasses. Usually three kind form of jaggery practices in the market such as solid jaggery, liquid jaggery and granular jaggery.

Solid jaggery is prepared by the concentrating the sugarcane juice. For the preparation of solid jaggery the sugarcane juice is concentrated till the striking point temperature. The striking temperature of juice concentration for the preparation of solid jaggery ranges as 116-118℃. The daily use of jaggery may increases the human life span and play important role to heal the health issues like cold, cough with sputum, dry cough, indigestion, constipation due to presence of more nutrition and medicinal values. Jaggry is an also excellent cleansing agent that flushing out toxins from the body. Those who face more dust in their day by day life, generally industrial workers are highly recommended to take a daily dose of jaggery. In addition that the jaggery is the full fill of iron content. It helps to prevent from the problem of *anemia*. Solid jaggery contains sucrose (65-85 mg per 100 g) and inverts sugars (3-15 mg per 100 g). It also contains important minerals viz. Iron (10-13 mg per 100 g), calcium (40-100 mg per 100 g), magnesium (70-90 mg per 100 g), potassium (10-56 mg per 100 g), phosphorus (20-90 mg per 100 g), sodium (19-30 mg per 100 g), zinc (0.2-0.4 mg per 100g), copper (0.1-0.9 mg per

100 g) and chloride (5.3 mg per 100 g).Vitamins are present in jaggery such as vitamin A, vitamin B1, vitamin B2, vitamin B5, vitamin B6, vitamin C, vitamin D2 which can be made available to the masses to mitigate the problems of malnutrition and under nutrition. Also the consumption of jaggery helps to purifies the blood, prevents rheumatic afflictions and bile disorders. The magnesium presence in jaggery strengthens the nervous system, helps to relax the body muscles, provides relief from fatigue and takes care of our blood vessels (Singh *et al.* 2013).

Liquid jaggery is another sweetener obtain by concentrating the purified sugarcane juice by evaporating the water upto the striking point temperature ranges as 103-106℃. Liquid jaggery is a semi-liquid syrup like an intermediate product. It has also great nutritive and medicinal benefits like solid jaggery. Liquid jaggery contains sucrose (40-60 mg per 100 mg), invert sugar (15-25 mg per 100 mg), calcium (0.30 mg per 100 mg), iron (8.5-10 mg per 100 mg), phosphorus (0.5 mg per 100 mg) and protein (0.10 mg per 100 mg) (Singh *et al.* 2011).

The granular jaggery is also another sweetener obtain by concentrating the purified sugarcane juice upto the striking point temperature ranges as 120-122℃. This temperature found to yield quality granular jaggery with good colour, friability and crystallinity. During the process the concentrating slurry is rubbed with wooden scrappers in order to develop the small crystal like formation, then cooled and sieved. Usually less than 3 mm size crystals are found to be better for quality granular jaggery. Granular jaggery packed into moisture proof polyethylene polyester laminates and PET bottles having moisture content reduced to less than 2% that can be stored for longer time (more than two years) even during monsoon period with little changes in quality (Nath *et al*. 2015).

Jaggery production process involves crushing of sugarcane, boiling and concentration of sugarcane juice, moulding into standard shape, size and packaging in suitable packages. The production process of jaggery generally performed on the furnace. There are many types of furnace designs available in India such as single, double, triple, and four pan furnaces. The main variation in design of the furnaces such as the number and size of pans uses, size and geometry of the flue gas channel, combustion chamber, height of the chimney and air supply system etc.

The different type of furnace design available in India. Generally in Uttar Pradesh and Uttarakhand, three pan jaggery furnace popular, however in Maharastra, single pan and four pans furnace are popular. The main part of construction of jaggery furnace involves combustion chamber, fuel feeding hole, chimney, and ash chamber (Agalave, 2015).

The major drawbacks with the most of the common furnaces are their excessive consumption of bagasse, more time taken for jaggery prepration and low thermal efficiency. An efficient furnace consumes minimum bagasse. Also many others problems found on the common furnace such as low water evaporation rate and improper combustion of fuel inside the combustion chamber. Water evaporation rate depends upon the thickness of pan and heat utilization efficiency of the furnace. Proper amount of air availability and proper moisture percentage of bagasse is important for good combustion of fuel during furnace operation which reduces energy losses through improper fuel combustion. The percentage of the more carbon dioxide present in the flue gas is also good indication of proper fuel burning inside the combustion chamber (Kulkarni and Ronge, 2018).

To overcome the such problem as mention above an efficient furnace are required to improve the completion of bagasse to enhance the thermal efficiency as well as water evaporation rate during the jaggery preparation. The ICAR-Indian Institute of Sugarcane Research has developed an improved three pan furnace for enhancing the recovery and efficiency along with increased quality of the jaggery. Based on the above facts the present research project entitled, **"Performance evaluation of IISR three pan furnace for jaggery making**" had been carried out with the following objectives.

1. To observe the temperature of sugarcane juice at different time interval and evaluation of water evaporation rate of pans during the jaggery making process.
2. To analyze the flue gas and evaluation of the requirement of bagasse per kg jaggery production.
3. To evaluate the thermal efficiency and jaggery production efficiency of the furnace.

CHAPTER-II
REVIEW OF LITERATURE

This chapter gives a brief account of available literature related with the proposed area of research under different heads and sub-heads. Many researchers have been carried out various experiment related to the processing of jaggery and parameters reviewed thoroughly. The design and development of the furnace, nutritional and medicinal values of the jaggery have also been briefed.

2.1 Status of the Jaggery Production and Quality of Jaggery

Rao *et al.* (2007) conducted the survey to find out the total jaggery production in the world. They reported that India contribute 70% of the world's jaggery production. Further they mentioned that jaggery production requires low capital requirement in production of jaggery as compare to white sugar. Also they reported that jaggery production is an important rural-based cottage industries and it has many nutritious and medicinal properties which helps to prevent from various disease such as cough ,cold, fatigue, *anemia* etc.

Khumbhar (2016) conducted the survey at the 25 random units of *gur* manufacturing of the major cluster of Kolhapur district of Maharastra. He reported that the *gur* profile of Kolhapur district was good specialty regarding golden color, chemical-free, pure and hygienically produced. Further he also mentioned that the health benefits of Kolhapuri *gur* as it rich in vitamins and minerals. It is also useful for the strengthening of the nervous system, relaxation of muscles, relief from fatigue, clarification of blood vessel and antioxidant property helps to scavenge free radicals from the human body. Further, also he analyzed an economic analysis of *gur* producing units considering cost and return, efficiency ratio and profitability ratio. He concluded that an efficiency ratio of 1.33 and a profitability ratio of 0.338 was found in *gur* production.

Nath *et al.* (2015) found that the production of sugarcane was 300 Mt in which 53% used for the production of white sugar, 36% into jaggery and *khandsari*, 3% as cane juice and 8% as seed cane. They also mentioned that jaggery has excellent anti-toxic and anti carcinogenic effects. They also discussed about the manufacturing of sugar, *gur* and *khandsari* and value addition which increases the quality of jaggery for human consumption.

2.2 Jaggery Processing Methods and Its Nutritional and Medicinal Benefits

Pawar *et al.* (2017) reported that the various jaggery production methods in different places such as the Indian Institute of Sugarcane Research (IISR), Lucknow, Regional Sugarcane and Jaggery Research Station, (RSJRS), Kolhapur, Regional Agricultural Research Station, (RARS), Anakapalle etc. They observed some technological developments in the processing, storage, and packaging of jaggery. Various institutes and several scientists are working on jaggery processing and preservation. They also found that the IISR, Lucknow had developed various processing equipment (pan) and standardized the manufacturing process for hygienic preparation of jaggery. Further they also mentioned that organic jaggery was becoming popular in the market because of its health benefits and good quality attributes, the herbal clarificants play a key role in chemical-free jaggery production.

Rajesh *et al.* (2016) found that jaggery contains more minerals and vitamins as compare the refined sugar. The mineral content includes calcium, phosphorus, magnesium, potassium iron, zinc, copper and vitamin content such as vitamin A. vitamin B, vitamin B1, vitamin B2 and folic acid . They also mentioned that jaggery has good source of energy, it also prevents rheumatic afflictions, prevents disorders of bile, helps in relieving fatigue, relaxation of muscles, maintains blood pressure, increases hemoglobin level and prevents from the *anemia*. .

2.3 Design and Development of the Furnace

Madan *et al.* (2004) studied the design and development of the furnace. They made an effort to design the cross section of the chimney that was circular in shape with masonry structure. They provided the sliding dampers into the chimney to produce and control the draft created below the furnace. They also designed a firing platform for fast bagasse feeding and fire grating for proper air circulation and combustion of bagasse. Further they also concluded that for the production of 1 kg jaggery would be consumed 2.24 kg bagasse which was also enhanced 1.96 kg/kg jaggery in the furnace.

Arya *et al.* (2013) made an effort to design of three pan jaggery making furnace. They found that the furnace was made with fire bricks, fire grates and improved chimney using dampers. In addition, they observed that three boiling pans of 457-559 mm thickness and 1524-1575 mm diameter were made of mild steel. Moreover the fire bricks (40- 50 percent alumina) were used in place of ordinary masonry bricks to construct the improved design of furnace. The chimney was also upgraded through circular cross sectional and the strengthened the chimney with an optimal height. This type of strengthened chimney provided the smooth flow of combustible exhaust gases with sufficient draft. They also observed that the improved unit resulted the less bagasse consumption about 12 % and increases in jaggery output potential of about 23 %.

Anwar (2009) conducted experiment through modification of pans for fuel and energy saving in open pan jaggery furnace. In his study concept of fins had been used for heating purposes for improving the efficiency of open pan jaggery making furnace. He reported that the heat utilization efficiency of the furnace increased considerably by using modified pans using fins. Parallel fins were provided to the bottom of the main pan and gutter pan of the IISR Lucknow 2-pan furnace. This concept based on the movement of flames and hot flue gases generated due to the combustion of bagasse and modification resulted in the saving of fuel and energy. He also observed that modified pan heat utilization efficiency increased from 20.12% to 29.56% in case of conventional pans.

Madan rao *et al.* (2017) evaluated the thermal efficiency of traditional single pan jaggery furnace and modified single pan jaggery furnace. They found that due to improvements by using fins in the conventional plant, the thermal performance of the traditional jaggery plant grew by 9.15 percent.

Rajigare *et al.* (2018) made an effort to modify the jaggery making pans using baffles. Jaggery making system has an existing system in which pan with baffles was used as a heating chamber. Further, they observed that the steam gives heat to the surface area of the pan during jaggery making. They also mentioned that the thermal performance of the jaggery processing plant would be improved by the improved design of the pan and chimney. They also compared between the improved plant and the conventional plant and resulted that the improved jaggery plant systems have higher efficiency than conventional jaggery making plant.

2.4 Performance Evaluation of the Jaggery Furnace

For the performance evaluation of the furnace the various particulars determined such as juice boiling rate, bagasse consumption, water evaporation rate, jaggery producing rate, juice boiling per kg of bagasse consumed, energy utilization in juice concentration and energy supplied through bagasse. Bagasse is the fibrous part of sugarcane left after crushing. It is the main residue of sugarcane left after the extraction of juice. Bagasse is directly used as a fuel in all sugar and jaggery manufacturing plants.

2.4.1 Water evaporation rate of the pans of the furnace

Shanker *et al.* (2012) conducted the experiment about the performance evaluation of different open pan furnace systems used for jaggery making. They observed that in a single pan furnace system, the desired consistency of juice (striking point) for jaggery making reached after 3 hr 50 min of bagasse feeding into the furnace. The total time taken to complete one cycle in the single pan furnace was 3 hr 50 min. They also observed that in single, double, triple, and four pan furnace systems having boiling rates of juice was 130.54, 200,257.29 and 324.15lit./hr, respectively. Further, in addition of the evaporation rates of water were also observed and measured as 106.27, 162.80, 209.43 and 263.85 lit./hr respectively in single, double, triple, and four pan furnace systems. The saving of bagasse and overall efficiency of single, double, triple and four pan furnace systems was 12.08 kg, 31.43 kg ,43. 29 kg and 16.17 %, 20.58 % and 25.14 % respectively.

Singh *et al*. (2009) evaluated the performance of two pan furnaces for jaggery making. They reported that the rate of water evaporation was 60.4 kg /h. The overall efficiency of the two pan furnace was 29.3%, which was higher than the single pan furnace efficiency of 19.7%. Further they also found that the saving of 34.82% in the operating cost of jaggery making in the case of two pan jaggery furnace as compare other conventional jaggery making furnace.

2.4.2 Analysis of flue gas, requirement of bagasse and heat losses

Todka *et al*. (2014) investigated about the waste heat recovery system to increase boiler efficiency. They conducted the research work in the sugar factory.

They analyzed the combustion exhaust gases and observed that the carbon dioxide gas percentage was more as compare other gasses in the flue gas also the temperature of the flue gas was measured as 200°C. The heat loss of the boiler, due to moisture formed by burning, dry gases and more moisture present in fuel was 11.55%, 16.96 %, and 14.22%. Further they estimated that the thermal efficiency of the furnace was 53.31%.

Sardeshpande *et al.* (2010) evaluated the thermal performance of four pan jaggery furnace. In the experiment the procedure was used to evaluate the thermal performance including mass and energy balance. They also include that the theoretical energy required for jaggery processing was only 29 % of the total energy supplied by bagasse combustion. Moreover the major losses occurred due to heat carried in flue gas and wall loss. Also, they found that the uncontrolled firing rate of fuel was leading to losses due to incomplete combustion. In addition, the air available for combustion depends upon the draft created by the chimney. They also mentioned that for production of 1 kg jaggery would required 1.73 -2.39 kg.

2.4.3 Thermal and jaggery production efficiency of the furnace

Madan rao *et al.* (2017) evaluated the thermal efficiency of traditional single pan jaggery furnace before and after the modification the furnace. They found that due to modification of the furnace the thermal efficiency was increased by 9.15 % as compare to the traditional jaggery making furnace.

Agalave (2015) enhanced the single pan conventional jaggery producing furnace by using fins and baffle. In his research, the principle of fins and baffles was used for the heating purpose, to increases the performance of open pan jaggery making furnace. Fins helped to focus further heat flow to the sugar cane juice and the baffle maintains the touch with flue gases. They also found that conventional furnaces, thermal efficiency improved by 9.44 percent, resulting in fuel and energy savings (31.34 %).

Anwar, (2009) studied the fuel and energy saving in open pan furnace used in jaggery making through modified pans. He found that the furnace's heat consumption efficiency significantly improved when using modified pans with fins. The modification resulted in fuel and energy conservation. The idea of fins was used for heating purposes in his research to increase the performance of open pan jaggery making furnace. The main pan and gutter pan of the IISR Lucknow were provided with parallel fins at the bottom. It was focused on the flames and hot flue gases created by the bagasse combustion process. This modification of pans increased the thermal efficiency from 20.12% to 29.56% of the furnace.

Shankar *et al.* (2012) evaluated the performance of different open pan furnace systems used for jaggery making in Karnataka. They observed that boiling rates of juice were measured as 130.54, 200 and 257.29 lit/hr, in single, double and triple pan furnace systems respectively. In addition, the water evaporation rate of the furnace was measured as 106.27, 162.80 and 209.43 lit/hr respectively in single, double and triple furnace systems. In addition the overall thermal efficiency of the single, double, triple pan furnace was measured as 16.17 %, 20.58% and 25.14%.

Singh *et al*. (2009) evaluated the performance of two pan furnace for jaggery making. They observed that the existing furnace had low fuel efficiency and required more fuel during the operation. Moreover the two pan jaggery furnace could concentrate the juice at the rate of 71.58 kg/h. It could evaporate 1.92 kg of water with 1 kg of bagasse. The rate of water evaporation was found to be 60.4 kg /h. The overall efficiency of the furnace was 29.3%, which was higher than the single pan furnace efficiency of 19.7%.

Manjare and Hole, (2016) studied the exhaust heat recovery and performance improvement of jaggery making furnace. They observed that in traditional single pan jaggery furnace, due to incomplete combustion of bagasse, energy losses were high resulting in higher fuel consumption and low thermal efficiency of the plant. To reduce the losses and cut down the consumption of bagasse, exhaust heat was utilized for the preheating of sugarcane juice in the pre-heater. The improved plant and the conventional plant were compared based on thermal efficiency and bagasse consumption per kilogram jaggery production. They established that the thermal efficiency was improved from 16.16% to 24.36% and the bagasse consumption was reduced by 1.2 kg per kg jaggery of production.

CHAPTER-III

MATERIALS AND METHODS

This chapter deals with the information related to raw materials used, details of methodologies used to conduct different experiments to achieve the objectives. The chapter describes the procedures for determination of different parameters, equipment and instruments used along with their specifications. The entire chapter is divided in different heads and sub-heads.

3.1 Experimental Site

All the experimental work was carried out using jaggery unit at the experimental field of Division of Agricultural Engineering, ICAR- Indian Institute of Sugarcane Research, Lucknow (U.P.).

3.2 Collection of Raw Materials

Fresh sugarcane was procured to conduct the entire experiment. Fresh and matured sugarcane was harvested from the farm of the ICAR-Indian Institute of Sugarcane Research, Lucknow. This is a commonly growing sugarcane variety *CoLk*-94184 that was used to perform the operation.

Fig 3.1: Sugarcane (*CoLK*-94184)

3.3 Constructional Detail of the Three Pan Furnace

The process of jaggery preparation involves the juice extraction, clarification, heating/ boiling and then cooling. Heating of cane juice was carried out step by step in different boiling pans. The jaggery formation starts when the temperature reaches to striking point during boiling of cane juice. The main parts of the furnace are discussed below.

3.3.1 Primary pan

Primary pan is also known as boiling pan where cane juice was heated upto a striking point and jaggery was prepared. The primary pan was made of mild steel (IS2062). It was only pan which was placed above the combustion chamber at 1219.2 mm height from the bottom of the ground. The outer and inner diameter of the boiling pan was 1828.8 mm, 1737.3 mm respectively. The depth of the pan was 277.3 mm along with a concave bottom. The primary was considered as the third and main pan where the juice concentration was takes place.

3.3.2 Secondary pans

Secondary pan involves two pans which were place adjacent by one another. The outer and inner diameter of the secondary pan was 1828.8 mm, 1737.3 mm respectively. The depth of both the secondary pans was pan 277.3 mm along with concave bottom. These pans were placed just above the passage line of flue gas escaping from the combustion chamber. The first and second secondary pans were placed at 1828.8 mm, 1524 mm height above from the ground respectively. In the secondary pans the juice was heated by utilizing the waste heat of the flue gas that escapes through the chimney.

3.3.3 Chimney

It was built of masonry structure with 3657.6 mm height from the ground surface level. The wall thickness of the chimney was 63.5 mm. The internal opening of the chimney was square in shape and dimension was 330×330 mm^2 Chimney was made to allow exit of flue gases from combustion chamber of the furnace

3.3.4 Flue gas passage

An arrangement was made to escape the hot exhaust gases below the ground surface. Passage was made with fire bricks in square shape and connected from the combustion chamber to chimney. This passage was square in shape having 300 × 300 mm^2 cross-sectional area. The length of this passage was 4267.2 mm. The hot gases were directed to escape from the combustion chamber to chimney hole towards the open atmosphere. The exhaust flue gases were used to pre-heat the cane juices in secondary pans before reaching to the boiling pan.

3.3.5 Step grate

It was an iron rod which was mounted 914.4 mm height. The number of iron rod was fitted with parallel arrangement for making the platform for burning of bagasse into the combustion chamber. The bagasse was fed to the step grate into the combustion chamber and the burning of bagasse take place. The ash pit was available below the step grate to collect the ash after burning the bagasse.

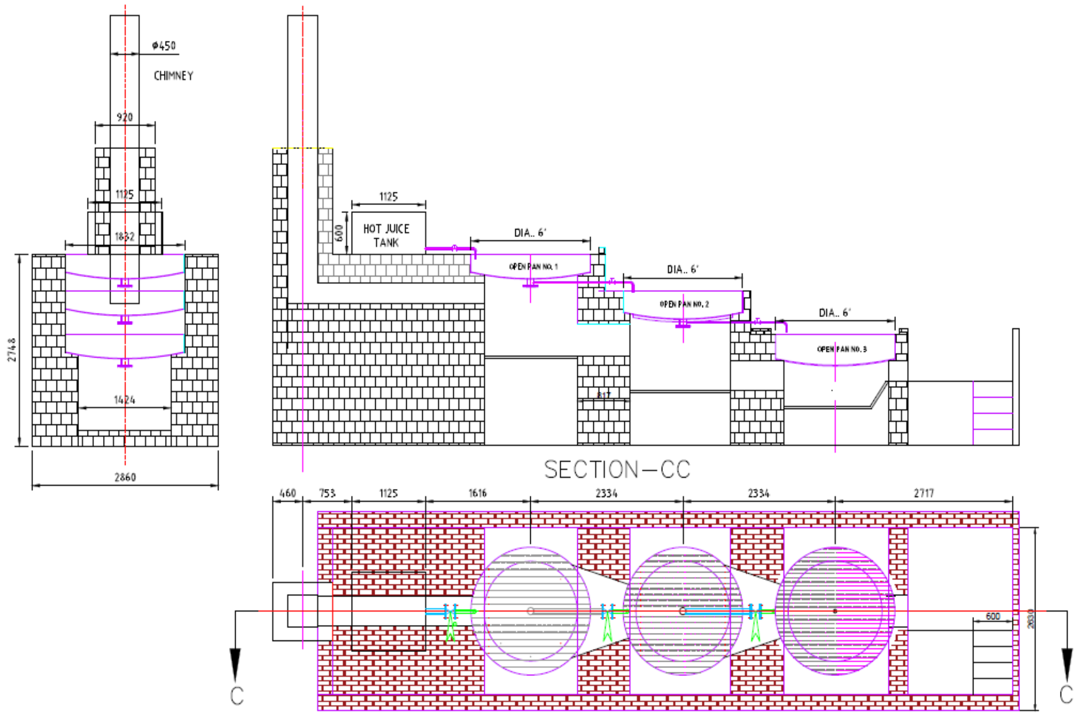

Fig 3.2: Constructional detail of IISR three pan furnace

3.3.6 Combustion chamber

A deep chamber was made with masonry structure below the ground surface for combustion of bagasse. The diameter and height of the combustion chamber was 1219.2 mm, 1828.8 mm respectively. The boiling pan was installed just over the combustion chamber. An additional man hole from the ground surface was made just beside the chamber to remove the ash from the combustion chamber. Another, purpose of this hole was to facilitate the proper air circulation for complete combustion of bagasse fed into the combustion chamber.

Fig 3.3: IISR three pan furnace

3.4. Measurement of Atmospheric Temperature and Relative Humidity

Digital temperature and RH meter (HTC, 103CTH) were used to examine the atmospheric temperature and relative humidity during the jaggery preparation. The atmospheric temperature and RH was measured as 25°C, 60% respectively.

Fig 3.4: Measuring atmospheric temperature and RH

3.5 Determination of Moisture Percentage of Bagasse

Halogen moisture balance (WENGER, HMB100) was used to measure the moisture percentage of bagasse. The halogen moisture meter consists of a halogen lamp through which the sample was heated. The moisture content was calculated based on the initial and final weight difference by moisture meter. The final moisture percentage of the bagasse was measures as 8-10%.

Fig 3.5: Measuring the moisture percentage of bagasse

3.6 Measurement of Total Soluble Solid (TSS)

A refractometer (VECTOR, ATAGO) was used to determine the total content of soluble solids (TSS) of the sugarcane juice. A drop of cane juice was used for sampling and press the red button for checking. The TSS of sugarcane juice was measured as 20 °Brix.

Fig 3.6: Measuring TSS of sugarcane juice

3.7 Measurement of the Juice Temperature

A digital thermometer (EXTECH, ST9283B) was used to measure the temperature of sugarcane juice during the operation. The sensing probe of the thermometer kept into contact with boiling juice to record the temperature. The initial and final temperature of the juice was measured as 22°C, 118°C respectively. The minimum and maximum temperature sensing range was -50°C to +200°C respectively

Fig 3.7: Measuring the juice temperature

3.8 Measurement of Furnace Temperature

An infrared thermometer (ETEKCIT, IRT-550P) was used to record the temperature in the combustion chamber as well as boiling juices. The temperature of the furnace was measures as 665℃ during the operation. The minimum and maximum measuring temperature range of the IR thermometer was -50 ℃ to +550℃ respectively.

Fig 3.8: Measuring the furnace temperature

3.9 Measurement of Flue gas Temperature

A flue gas analyzer (ACE, 8000) was used to measure the concentrations of various gases present in the flue gas and temperature. The sensing probe of analyzer was connected to the gas analyzer. During the operation the sensing probe was kept in contact with escaping exhaust gases. The temperature of the flue gas was measured as 270-290℃ during operation.

Fig: 3.9: Measuring temperature of the flue gas

3.10 Preparation of the Clarificants

Fresh deola (*H. ficulneus)* was used as a clarificants for the preparation of jaggery. It is also known as vegetative clarificants "*Okra*". For the preparation of the deola solution, stalks of the deola was crushed properly and mixed with water. When the proper concentration was obtained in the solution then filtered it. Further, the crushed stalk of deola was removed from the solution. Thus, total 13 kg deola solution was prepared for the one batch of jaggery preparation.

3.11 Jaggery Preparation

The fresh sugarcane was used for the preparation of the jaggery. It was crushed through crusher having the 60% of juice recovery and extracted juice was collected in settling tank. Then it was carried to the furnace by using the pump.

Procedure:

Freshly extracted sugarcane juice was poured into the primary and secondary pan with help of measuring metal cane. Firing in the combustion chamber was started just after the pouring of sugarcane juice to allow the boiling and evaporation of the containing moisture for the preparation of the jaggery. Continuous bagasse feeding was done to maintain the optimum heat required for completion of the process. During the operation a known amount of clarificants was added into the boiling juice in order to remove the impurities in the form of scum. Apart from 10-15 ml of mustard seed cooking oil that helps to remove the impurities and to impart the good colour in the final product. The scum layer was periodically removed from the boiling pan with the help of long metal spoon like arrangement. Stirring of boiling juice was continuously done to prevent the spilling off the juice form the boiling pan. The juice temperature and concentration was regularly, monitored and recorded using digital thermometer till the completion of the process. Boiling of sugarcane was continues to attain the striking temperature in order to form the solid jaggery. After attaining the temperature 116°C to 118°C the concentrated juice was removed from pans and transferred to a wooden trough for cooling for the and then moulded in standard cube shape frames.

Fig 3.10: Jaggery preparation process

3.12 Weighing of the Produced Jaggery

An electronic weighing balance (TOYO, KD700) was used for the weighing prepared jaggery. The total production of jaggery was measured as 95 kg per batch. The maximum weighing capacity of the weighing balance was 1000 kg and the least count was 0.1.

Fig 3.11: Weighing of jaggery produced

According to Sahu, (2018) the jaggery production process was given below

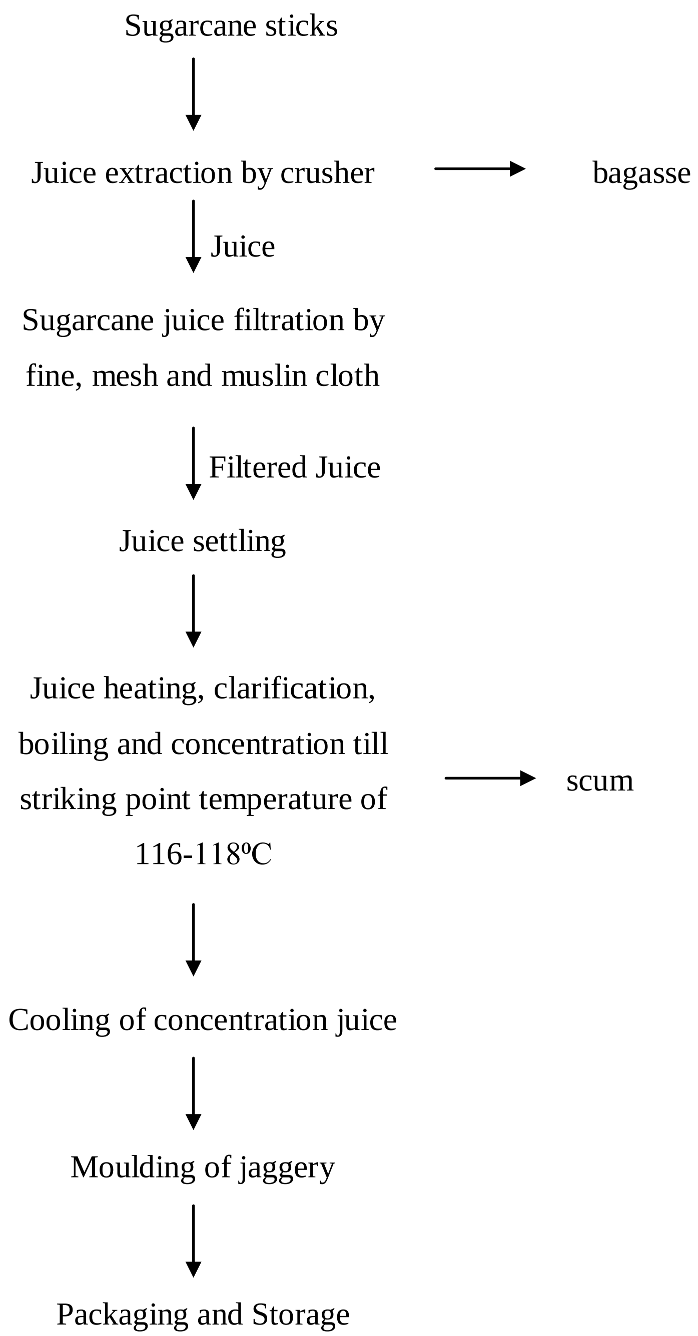

Fig 3.12: Flow chart of jaggery production process

3.13 Striking Point Temperature

The desired consistency of the sugarcane was required for the preparation of quality jaggery. The temperature required for reaching the desired concentration of cane juice during jaggery making is known as the striking point temperature of jaggery. In the traditional furnaces the different type of the jaggery preparation takes place such as solid, liquid and granular jaggery which require the different striking point temperature. The striking temperature for solid jaggery preparation was 116-118℃. In addition, for the preparation of liquid jaggery and granular jaggery required striking point temperature as 104-106 and 121- 123℃ respectively.

3.14 Temperature Variation of Pans During Jaggery Preparation

When started the jaggery preparation, first recorded the ambient temperature, relative humidity of the atmosphere. The initial temperature of the juice was also recorded. Then started the first boiling operation and the temperature of the juice of three pans was measured continuously at the 15 minutes intervals till the reaching striking temperature of the primary pan. When the juice of the primary pan (boiling pan) reached the desired consistency (116- 118℃). Then the concentrate juice was removed from the primary pan and further cooled and then moulded into the desired shape. The time and temperature variation of the first boiling operation was recorded.

The juice from the second pan was transferred to the primary pan and the juice of first pan transferred to the second pan and started second boiling operation. When the juice reached the striking point temperature in the second boiling operation. Then it was removed for cooling and its total time consumption was recorded. Again third boiling operation was started by transfer of the juice from second pan to primary pan. The total time consumption of third boiling operation was recorded. Thus the three boiling operation performed continuously at one batch of jaggery preparation.

3.14.1 Determination of water evaporation rate

. The water evaporation with respect to time and bagasse consumption of the pans was determined by using equation 3.1, 3.2 and 3.3 (Singh,2009)

$$(W_{jaggery}) = W_{juice} + W_{deola\ solution} - W_{water} - M_{scum} \quad \text{....(3.1)}$$

$$\text{Water evaporation rate} = \frac{Wwater}{T} \quad \text{....(3.2)}$$

Water evaporation per kg of bagasse consumed = $\frac{W_{water}}{B}$ ....(3.3)

Where,

W_{juice} = Weight of juice (kg)

$W_{jaggery}$ == Weight of jaggery produced per batch (kg)

$W_{deola\ solution}$ = Weight of deola solution (kg)

W_{scum} = Weight of scum removed per batch (kg)

W_{water} = Weight of water evaporated during boiling (kg)

B = Weight of bagasse consumed (kg)

T = Time required for jaggery preparation (min)

3.15 Analysis of the Flue Gas Composition

Flue gas analyzer (ACE 8000) was used for the analysis of flue gas during the jaggery preparation. The probe of the flue gas analyzer was kept above the combusted exhaust gas at definite time interval after the fuel burning started into the combustion chamber. The concentration of the different gas was displayed on the gas analyzer displayed board which was recorded. The temperature of the exhaust gas was also recorded.

Fig 3.13: Analyzing of the flue gas contains

3.15.1 Determination of bagasse consumption

The total bagasse consumption per kg jaggery was determined by using the eqn.3.4, 3.5 (Singh ,2009)

Bagasse consumption (kg/min) = $\frac{B}{T}$ ...(3.4)

Bagasse consumed per kg of Jaggery (kg /kg jaggery) = $\frac{B}{W\ jag}$ ...(3.5)

Where,

B = Weight of bagasse consumed (kg)

T = Time required to reach the striking temperature (min)

W_{jag} = Weight of produced jaggery (kg)

Fig 3.14: Bagasse feeding during jaggery preparation

3.16 Determination of Thermal Efficiency of the Furnace

The thermal efficiency of the furnace was determined by the ratio of total energy output to the total energy input for jaggery preparation which was estimated by using the following eqn. (Manjare and Hole,2016)

$$\text{Thermal efficiency } (\eta_{thermal}) = \frac{Q_{outpu\ t}}{Q_{input}} \times 100 \qquad \ldots.(3.6)$$

Where,

Q_{output} = Total heat utilized for heating the juice (MJ)

Q_{input} = Heat energy input per batch (MJ)

$\eta_{thermal}$ = Thermal efficiency (%)

3.16.1 Determination of jaggery production efficiency of the furnace

The jaggery production efficiency was determined by the eqn. 3.6

$$\text{Jaggery production efficiency} = \frac{Q_{jag}}{Q_{juice}} \times 100 \qquad \ldots.(3.7)$$

Where,

W_{jag} = Weight of jaggery produced per batch (kg)

W_{juice} = Weight of sugarcane juice per batch (kg)

CHAPTER-IV
RESULTS AND DISCUSSIONS

This chapter deals with the details of results obtained from different experiments conducted to achieve the set objectives aimed to investigate. This also includes the observation of the temperature variation from the cane juice, the calculation of water evaporation rate of the pans, analysis of flue gases and calculation of the total consumption of bagasse per batch required for jaggery preparation. The thermal efficiency and jaggery production efficiency of the furnace was also calculated and presented in the chapter. The efforts have been made to present the results through suitable tables and graphs also to give a clear understanding of the obtained results.

4.1 Temperature Variation of Juice During the Furnace Operation

During the jaggery preparation process the temperature variation of the furnace was periodically recorded till the attainment of striking point of cane juice. Prior the boiling of the cane juice the initial climatic parameters as well as juice temperature and TSS was recorded. As per the observation the initial test parameter such as ambient temperature, relative humidity, initial juice temperature, total soluble solid (TSS) were recorded as 26℃, 60.50%, 22℃, 20°Brix respectively. Further the first boiling was started and the temperature was recorded after each 15 minutes interval. From the temperature observation it was noticed that the temperature of cane juice was increased continuously. The concentration process of juice was continues till the attainment of the striking point i.e. 117± 1℃ of the juice. The time required to reach the striking point temperature was found as 70 minutes for the first boiling operation during the preparation of solid jaggery. At the same time the temperature of the juice in the secondary pan 1 & 2 was 80℃ and 95℃ respectively. The reason behind the temperature enhancement of second and third boiling pan might be due to flue gas escaping through the inner passage flowing towards the furnace chimney. The waste heat was used by the heating of secondary pans. This was the benefit of the three pan furnace.

Again the second boiling operation was started by transferring the juice from second pan to boiling pan and first pan to second pan. The total time required to reach the striking temperature of the juice during the second boiling operation was recorded as 55 minutes. Further the third boiling operation was started by the transferring the sugarcane juice from the second pan to the boiling pan. The total time taken during the third boiling operation was noted as 45 minutes to attain the striking point temperature for solid jaggery preparation. Thus three boiling operation was performed continuously in one batch and total time recorded was 2 hours 50 minutes for solid jaggery preparation. The temperature observation of the sugarcane juice was recorded in the table and given in the Appendix A.

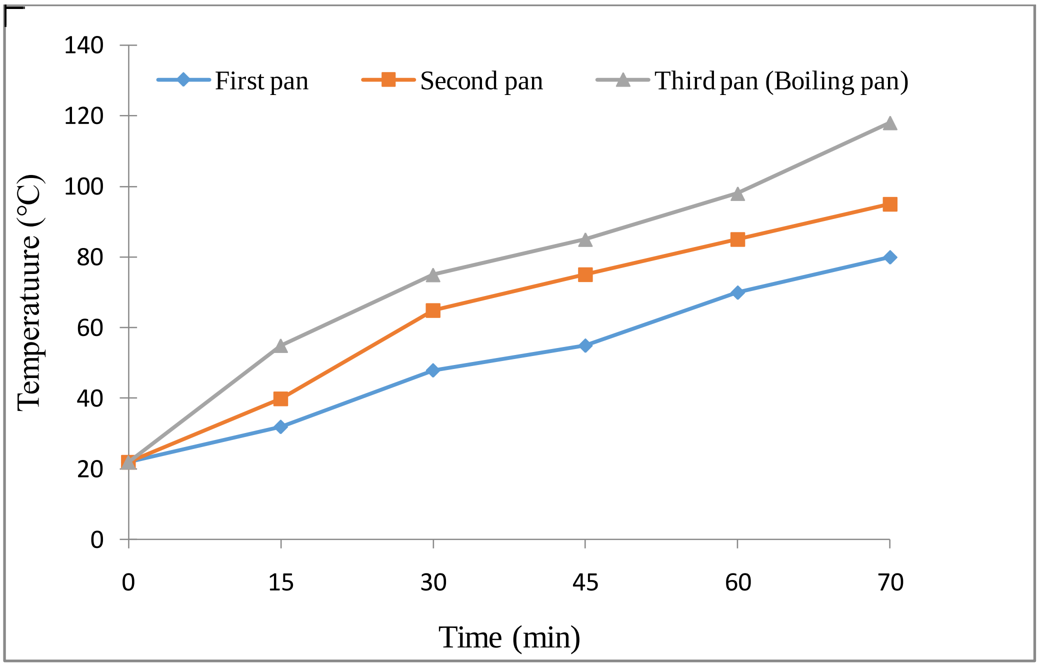

Fig 4.1: Temperature profile of pans during furnace operation of the first batch

4.2 Temperature Variation of Juice Under Steady State (Pre-heating) Condition of the Furnace

During the solid jaggery preparation the initial temperature of the sugarcane juice was recorded as 26°C at the starting of second batch. The temperature of the juice was recorded after each 15 minutes interval. The time required to attain the striking point temperature in first boiling operation was recorded as 50 minutes. The saving of time (as compare first batch) in first boiling operation was due to fact that initial temperature of the boiling pan was higher. At the same time, the juice temperature of the pan 1 and 2 was 70℃, 90℃ respectively. The reason behind the temperature enhancement of second and third boiling pan might be due to the flue gases escaping through the inner passage flowing towards the furnace chimney.

Again second boiling operation of the juice was started by transferring of the juice from the second pan to the boiling pan and first pan to the second pan. The time required to attain the striking point temperature was recorded as 45 minutes. Further the third boiling operation was started continuously by transferring of sugarcane juice from the second pan to boiling pan. The time consumption to attain the striking point temperature was 40 minutes. Thus three boiling operation was performed continuously and the total time required for jaggery preparation was 2 hours 15 minutes in this batch. The observation temperature was recorded and given in the Appendix A.

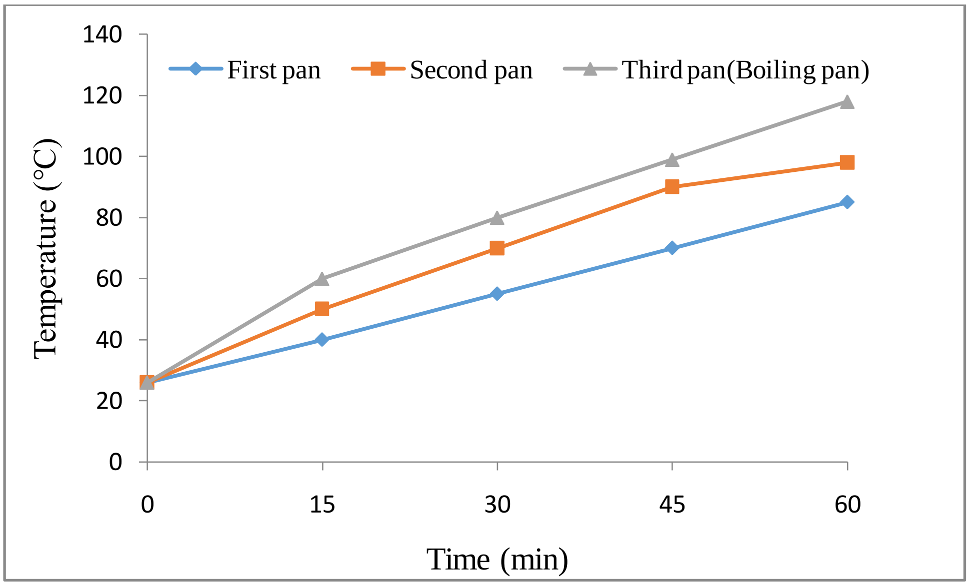

Fig 4.2: Temperature profile of pans under pre-heating condition

4.3 Determination of Water Evaporation Rate of the Pans

To fulfill the first objectives during jaggery preparation, the water evaporation per minute and per kg bagasse consumption of the furnace was calculated by using the equation 3.2 and 3.3 as 2.94 kg/min and 1.81 kg/ kg of bagasse respectively. Similar results were reported by Singh (2009). The water evaporation rate of improved three pan furnaces was 1.61 kg of water /kg bagasse. It depends upon the capacity of cane juice used in the pan for jaggery preparation.

4.4 Analysis of the Flue Gas During Furnace Operation

During the entire process the furnace performance and flue gases was analyzed at each 15 minutes interval. The flue gas analyzer was used to measure the mixture gases and their average concentration. It was found that CO and CO_2 was detected by the gas analyzer. From the experiment it was found that the concentration of CO & CO_2 varies between 0.010-0.016% and 0.030-0.40% respectively. The observation table was shown in Appendix B. The carbon dioxide percentage (CO_2) was always more than carbon monoxide (CO) in each batch. The presence of more carbon dioxide percentage in the flue gas indicates the good combustion of bagasse. Therefore, no energy losses occurred through unburnt bagasse into the combustion chamber of the furnace. The temperature of the flue gas was also recorded.

The average temperature of the flue gas was measured 280°C. The observation table was shown in Appendix B. The inside temperature of the furnace was recorded as 665°C during operation. Thus the heat utilization of the furnace was more and less heat losses occurred through flue gas during the whole batches of furnace operation.

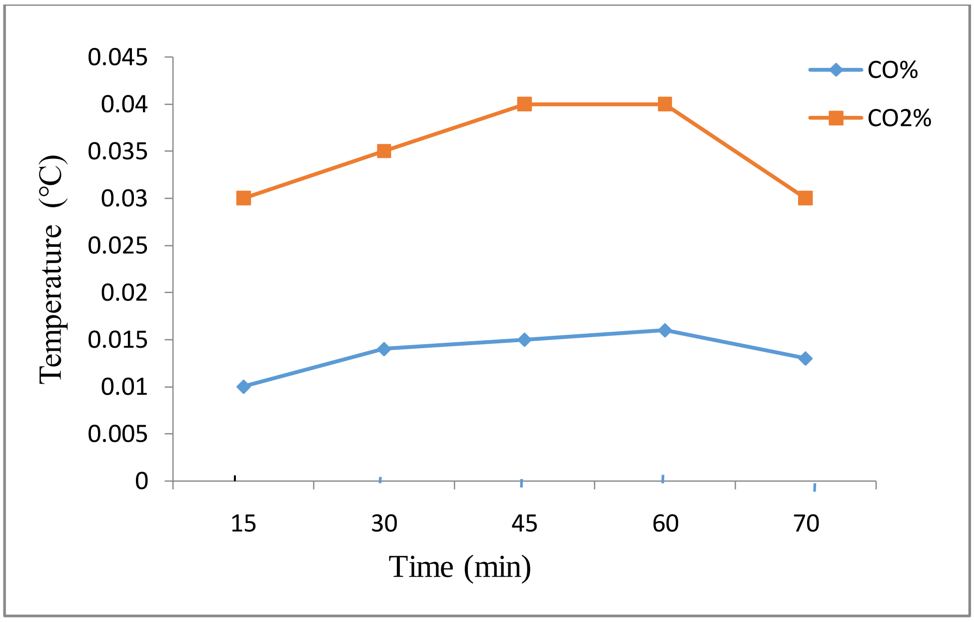

Fig 4.3: Temperature profile of flue gas contains during furnace operation

4.5 Determination of Bagasse Consumption Per Kg Jaggery Production

During the jaggery preparation the bagasse consumption with respect to time and jaggery production was calculated by using the equation 3.4 and 3.5 as 1.61 kg/min, 2.42 kg/kg jaggery respectively. The similar results reported by the Arya (2003). He was concluded in his research that traditional three pan furnaces required 2.37 kg bagasse for 1 kg jaggery production.

4.6 Determination of Thermal Efficiency and Jaggery Production Efficiency of the Furnace

The thermal efficiency and jaggery production efficiency was calculated by using the equation 3.6 and 3.7. From the experiment it was found that the thermal efficiency and jaggery production efficiency was recorded as 28.82%, 15.83% respectively. The experiment results shows that the three boiling operation of the IISR three pan furnace system for jaggery production was better as compare to other jaggery preparation furnace. The reason behind the enhancement of the thermal efficiency and jaggery production efficiency was might be due to improved design of flue gas passage as well as chimney. The improve design system allows the draft in the modified flue gas passage. The modified flue gas passage gives the maximum heat transfer towards the secondary boiling pan. Similar results were reported by Singh (2009). He was observed that the thermal efficiency of in his experiment of improved three pan furnaces was 21.70%. Rao (2003) obtained the thermal efficiency of 14.75 % in a single pan furnace and Singh (2009) got the thermal efficiency of 16-19 % in their two pan furnaces.

In the first batch of jaggery preparation, 95 kg of jaggery was prepared from 600 kg juice in 2 hours 50 minutes or 170 minutes. The amount of bagasse required in the first batch was 257 kg. Under the pre heating condition of the furnace (Batches 2-5) 95 kg of jaggery was prepared from 600 kg of juice. The time required for the preparation of the jaggery was also significantly higher in the first batch as compared to the average time required in the successive batches.

In IISR three pan furnace, total 2.42 kg bagasse was required for the preparation of 1 kg jaggery. Arya (2003) concluded in his research that traditional three pan furnaces required 2.37 kg bagasse for 1kg jaggery production and after modification of its pan required 1.99 kg bagasse per kg jaggery production.

Kulkarni and Ronge (2018) also concluded in their research that three pan furnaces required 1.00-1.25 kg bagasse per kg jaggery production. The consumption of bagasse may be different due to variation in size and thickness of pans, design of chimney, the rate of bagasse feeding, design of furnace construction etc.

In IISR three pan furnace, the water evaporation rate was 1.84 kg per kg of bagasse. Singh (2009) reported the water evaporation rate of improved three pan furnaces was 1.61 kg of water /kg bagasse.

The jaggery production efficiency was 15.83% and the inside temperature of the furnace was 665°C. The flue gas temperature was 260-290°C which indicated that less heat was lost through flue gas and due to the presence of more carbon dioxide (CO_2) percentage as compared to carbon monoxide (CO) percentage in flue gas indicated good combustion of fuel into the combustion chamber. Arya (2013) observed the fuel gas in three pan furnaces and resulted that the combustion of fuel in his experiment was good due to the presence of more carbon dioxide (CO_2) percentage as compared to carbon monoxide (CO) percentage in the flue gas.

The overall thermal efficiency of the IISR three pan furnace was estimated as 28.82 % while Singh (2009) observed a thermal efficiency of 21.70% in his experiment of improved three pan furnaces. Rao (2003) obtained the thermal efficiency of 14.75% in a single pan furnace. Singh (2009) got the thermal efficiency of 16-19% in their two pan furnaces. The thermal efficiency also depends upon various parameters such as the size and thickness of the pan, the design of the chimney, the size of the flue gas passage, etc.

CHAPTER-V
SUMMARY AND CONCLUSION

This chapter deals with the description of summary and conclusion used to accomplish the experimental work done to attain the desired objectives of the study entitled, "Performance evaluation of IISR three pan furnace for jaggery making".

The results of the performance evaluation of the three pan furnaces of the ICAR-Indian Institute of Sugarcane Research, Lucknow are summarized as below.

1. The water evaporation rate of the furnace was 1.81 kg / kg of bagasse and the requirement of energy for the evaporation of 1 kg water was estimated as 2.25 MJ.
2. The analysis of flue gas was also observed using a gas analyzer. The percentage of carbon monoxide (CO) was less in all batches as compare the carbon dioxide (CO_2) percentage. Thus, the presence of more percentage of carbon dioxide in the flue gas is a good indication of fuel burning inside the combustion chamber during jaggery preparation process.
3. The overall consumption of bagasse per batch was 230 kg for the production of 95 kg jaggery from 600 kg juice. The requirement of bagasse for the production of 1 kg jaggery was estimated as 2.42 kg/kg jaggery. The average time taken for jaggery preparation per batch was observed as 2 hour 22 minutes.
4. The total energy requirement of energy (Q) for the production of jaggery per batch was 1193.278 MJ and the major energy losses (Q_{loss}) occurred during jaggery making was 2946.73 MJ.
5. The appropriate temperature of concentrated juice (slurry) for moulding in the cube size frame was 81°C in an open atmosphere.
6. The overall thermal efficiency of the furnace and jaggery production efficiency was estimated as 28.82%, 15.83% respectively of the furnace.

CONCLUSIONS

The finding of the present study indicated that ICAR –IISR three pan was a well-designed furnace in which sixth batches of jaggery preparation performed continuously in a single day to check furnace performance.

- The water evaporation rate and fuel burning inside the furnace was good during jaggery preparation.
- It also consumed less time and bagasse as compare other jaggery making furnaces and the presence of more percentage of carbon dioxide in the flue gas is a good indication of fuel burning inside the combustion chamber.
- The overall thermal efficiency of the furnace and jaggery production efficiency was estimated as 28.82%, 15.83% respectively

Thus, this furnace is more efficient and helpful to boost the income of farmers and jaggery production industries also.

Suggestion for Future work

1. A semi-automatic mechanical feeding system may be attached on this furnace for uniform feeding of bagasse.
2. Air blowers may be exercised for better combustion of bagasse.
3. Fins and baffles maybe provided below the pans, this would increase the efficiency of the furnace.
4. The waste heat recovery system can be attached to the IISR three pan furnace to improve its efficiency.

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APPENDIX-A

Table A-1: The average quantity of scum removed during furnace operation

S. No.	Pans	Amount of scum removed(kg)					Average scum removed (kg)
		B1	B2	B3	B4	B5	
1	Pan1	38	30	30	36	33	100
2	Pan2	32	35	35	37	37	
3	Pan3	32	30	38	28	35	
	Total	102	95	103	95	105	

Table A-2: The average jaggery produced during furnace operation

S.No.	Pans	Jaggery produced(kg)					Average jaggery production per batch (kg)
		B1	B2	B3	B4	B5	
1	Pan1	33	30	30	30	33	95
2	Pan2	30	32	30	33	32	
3	Pan3	32	35	33	32	30	
	Total	95	97	93	95	95	

Table A-3: The average consumption of bagasse during furnace operation

S.No.	Pans(P)	Bagasse consumption(kg)					Average jaggery production per batch (kg)
		B1	B2	B3	B4	B5	
1	Pan1	64	50	50	50	43	230
2	Pan2	90	80	80	70	70	
3	Pan3	118	105	100	90	90	
	Total	272	235	230	210	203	

Table A-4: The average time consumed during furnace operation

S.No.	Pans	Time consumption(min.)					Average time consumed per batch (Min.)
		B1	B2	B3	B4	B5	
1	Pan1	40	40	35	35	35	142
2	Pan2	50	45	45	40	40	
3	Pan3	60	50	50	50	50	
	Total	170	150	135	130	125	

(Note:- B1=First batch, B2= Second batch, B3= Third batch, B4=Fourth batch, B5=Fifth batch)

APPENDIX-B

Table B-1: Temperature variation of juice during the first batch operation

S. No.	Time (Min.)	Juice Temperature (°C)		
		First pan	Second pan	Third pan (Primary pan)
1.	0	22	22	22
2.	15	32	40	55
3.	30	48	65	75
4.	45	55	75	85
5.	60	70	85	98
6.	70	80	95	118

Table B-2: Temperature variation of juice under steady state (pre-heating) condition of the furnace

S. No.	Time (Min.)	Juice Temperature (°C)		
		First pan	Second pan	Third pan(Primary pan)
1.	0	26	26	26
2.	15	40	50	60
3.	30 .	55	70	80
4.	45	70	90	99
5.	60	85	98	118

- **Determination of Water Evaporation Rate**

The important parameters was given below for the calculation of water evaporation rate by using the eqn. 3.1, 3.2 and 3.3

Weight of juice (W_{juice}) = 600kg

Weight of bagasse consumed (B) = 230kg

Time consumed in the concentration of juice (T) = 142 minutes

Weight of jaggery produced per batch, ($W_{jaggery}$)= 95 kg.

Weight of deolasolution , ($W_{deola\ solution}$)= 13 kg

Weight of scumremoved per batch,(W_{scum}) = 100 kg

To calculate total weight of water evaporated-

$$(W_{jaggery}) = W_{juice} + W_{deola\ solution} - W_{water} - M_{scum}$$

$$95 = 600 + 13 - W_{water} - 100$$

$$W_{water} = 600+13 - 100 - 95$$

$$W_{water} = 418 \text{ kg}$$

$$\text{Water evaporation rate} = \frac{W_{water}}{T}$$

$$\text{Water evaporation rate} = \frac{418}{142}$$

Water evaporation rate = 2.94 kg /min.

$$\text{Water evaporation per kg of bagasse consumed} = \frac{W_{water}}{B}$$

$$\text{Water evaporation per kg of bagasse consumed} = \frac{418}{230}$$

Water evaporation per kg of bagasse consumed = 1.81 kg/ kg bagasse

- **Determination of Bagasse Consumption**

The important parameters was given to calculate the requirement of the bagasse per kg jaggery production by using the eqn. 3.4 and3.5

Weight of bagasse consumed(B) = 230 kg

Weight of jaggery(W_{jag}) = 95kg

Time consumed in the concentration of juice (T) = 142 minutes

$$\text{Requirement of bagasse per minute} = \frac{B}{T}$$

$$\text{Requirement of bagasse per minute} = \frac{230}{142}$$

Requirement of bagasse per minute = 1.61 kg/ min.

$$\text{Requirement of bagasse per kg jaggery production} = \frac{B}{W_{jag}}$$

Requirement of bagasseper kg Jaggery production = $\frac{230}{95}$

Requirement of bagasse= 2.42 kg bagasse / kg jaggery

- **Determination of Thermal Efficiency of the Furnace**

The important parameter was given for the calculation of thermal efficiency of the furnace by using the eqn. 3.6

Weight of sugarcane juice per batch, (W_{juice}) = 600 kg

Weight of bagasse required per batch, ($W_{bagasse}$) = 230 kg.

Weight of jaggery produced per batch, (W_{jag})= 95 kg.

Weight of deolasolution ($W_{deola\ solution}$)= 13 kg

Weight of scum removed per batch,(W_{scum}) = 100 kg.

Calorific value of bagasse, ($C_{bagasse}$)= 18000 kJ/kg (Kulkarni and Ronge,2018)

Specific heat of juice, (Cp_{juice}) = 4.184 kJ/kg K (Kulkarni and Ronge,2018)

Specific heat of jaggery (Cp_{jag}) = 2 kJ/kg K (Kulkarni and Ronge,2018)

The initial temperature of the juice, ($T_{initial}$) = 22 °C.

Final temperature of juice (T_{final})= 118°C

Striking temperature of jaggery ($T_{striking}$)= 118°C

latent heat of vaporization,(h)= 2270 kJ/kg (Kulkarni and Ronge,2018)

The temperature of evaporation of water ($T_{evap.}$) = 100° C

Total average time required for jaggery making (min) =142 minutes

Average consumption of bagasse = 230 kg

Energy required for heating the juice (Q_{juice}) = $W_{juice} \times Cp_{juice} \times (T_{juice} - T_{initial})$

$$Q_{juice} = 600 \times 4.184 \times (118 - 22)$$

$$Q_{juice} = 240.998 \text{ MJ}$$

Total energy for vaporization of water (Q_{water}) = W_{water} x h

$$Q_{water} = 418 \text{ x } 2270$$

$$Q_{water} = 948.860 \text{ MJ}$$

The energy required for jaggery production (Q_{jag}) = $W_{jag} \times Cp_{jag} \times (T_{striking} - T_{evap.})$

$$Q_{jag} = 95 \times 2 \times (118-100)$$

$$Q_{jag} = 3.420 \text{ MJ}$$

Theoretical total minimum energy required for jaggery making,

$$(Q_{output}) = Q_{juice} + Q_{water} + Q_{jag}$$

$$Q_{output} = 240.998 + 948.860 + 3.420$$

$$Q_{output} = 1193.27 \text{MJ}$$

The overall energy input energy per batch (Q_{Input}) = $W_{bagasse}$ x $C_{bagasse}$

$$Q_{Input} = 230 \times 18000$$

$$Q_{Input} = 4140.00 \text{ MJ}$$

$$\text{Thermal efficiency } (\eta_{thermal}) = \frac{Q_{output}}{Q_{input}} \times 100$$

$$\text{Thermal efficiency } (\eta_{thermal}) = \frac{1193.27}{4140} \times 100$$

$$\text{Thermal efficiency } (\eta_{thermal}) = 28.82\%$$

- **Determination of Jaggery Production Efficiency of the Furnace**

The important parameter was given for the calculation of for calculation of jaggery production efficiency by using the formula (eqn. 3.7)

Weight of jaggery produced per batch(W_{jag}) = 95 kg

Weight of sugarcane juice per batch (W_{juice}) = 600 kg

$$\text{Jaggery production efficiency} = \frac{W_{jag}}{W_{juice}} \times 100$$

$$\text{Jaggery production efficiency} = \frac{95}{600} \times 100$$

$$\text{Jaggery production efficiency} = 15.83\ \%$$

APPENDIX-C

Table C-1: Flue gas contains during furnace operation

S. No.	Time(T)	Flue gas contains	
		CO (%)	**CO_2 (%)**
1.	15	0.010	0.030
2.	30	0.014	0.035
3.	45	0.015	0.040
4.	50	0.016	0.040
5.	70	0.013	0.030

Table C-2: Temperature variation of flue gas during furnace operation

S.N.	Batches(B)	Flue Gas Temperature (°C)
1.	B1	270
2.	B2	280
3.	B3	280
4,	B4	290
5.	B5	280

(Note :- B1=First batch, B2= Second batch, B3= Third batch, B4=Fourth batch, B5=Fifth batch)

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