

**DEVELOPMENT AND PERFORMANCE
EVALUATION OF MANUALLY OPERATED
MACHINE FOR MAKING JAGGERY CUBES USING
JAGGERY POWDER**

M.Tech. (Agril. Engg.) Thesis

By

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EVALUATION OF MANUALLY OPERATED
MACHINE FOR MAKING JAGGERY CUBES USING
JAGGERY POWDER**

Thesis

**Submitted to the
Indira Gandhi Krishi Vishwavidyalaya, Raipur**

by

SHAILESH KUMAR MARKAM

**IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF**

**Master of Technology
in
Agricultural Engineering
(Agricultural Processing and Food Engineering)**

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CERTIFICATE – I

This is to certify that the thesis entitled “**Development and performance evaluation of manually operated machine for making jaggery cubes using jaggery powder**” submitted in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Shailesh Kumar Markam** 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 certified course. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

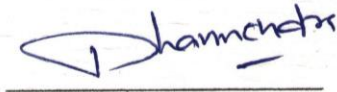

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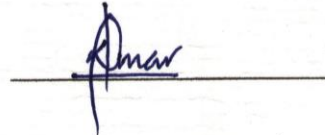

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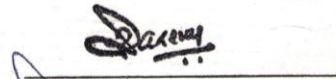
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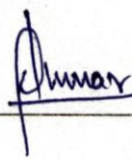
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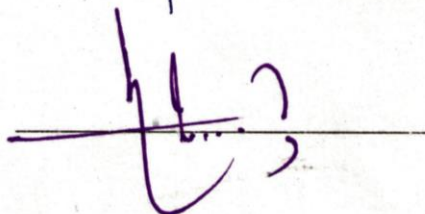
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Date:-----

TABLE OF CONTENTS

Chapter	Title	Page No.
	ACKNOWLEDGEMENT	i-ii
	TABLE OF CONTENTS	iii-vii
	LIST OF TABLES	viii
	LIST OF FIGURES	ix
	LIST OF PLATES	x-xi
	LIST OF ABBREVIATIONS AND SYMBOLS	xii-xiv
	ABSTRACT	xv-xx
I	INTRODUCTION	1-4
II	REVIEW OF LITERATURE	5-14
	2.1 Status of jaggery production in india	5
	2.2 Nutritional and medicinal importance of jaggery	6
	2.3 The production process techniques of different types of jaggery	8
	2.4 Properties of sugar and sugar cubes	11
	2.5 Engineering properties related to jaggery and jaggery powder	11
	2.6 Value addition in jaggery	12
	2.7 Projects related to the design and development of machine	13
III	MATERIALS AND METHODS	15-34
	3.1 Experimental Site	15
	3.2 Collection of Raw Material	15

3.3 Development of Manually Operated Machine for Making Jaggery Cubes Using Jaggery Powder	16
3.3.1 Preliminary experimental procedure for designing	16
3.3.2 Physico-chemical analysis of jaggery powder	18
3.3.2.1 Moisture content analysis	18
3.3.2.2 Sieve analysis	18
3.3.2.3 pH	18
3.3.2.4 Electrical conductivity	19
3.3.2.5 Bulk density	19
3.3.2.6 True density	20
3.3.2.7 Porosity	20
3.3.2.8 Total soluble solids (°Brix)	20
3.3.2.9 Color evaluation	21
3.3.2.10 Solubility	21
3.3.3 Development and fabrication of manually operated machine for making jaggery cubes	22
3.3.3.1 Working principle	22
3.3.3.2 Modelling and design consideration of the manually operated jaggery cube making machine	22
3.4 Development of Manually Operated Machine for Making Jaggery Cubes	24
3.4.1 Material estimation	24
3.4.2 Fabrication of machine	25

3.5 Performance Evaluation of Manually Operated Jaggery Cube Making Machine Using Jaggery Powder	27
3.5.1 Determination of machine capacity	27
3.5.2 Production time	28
3.5.3 Machine efficiency	28
3.5.4 Compressed Volume, Compressed Density, Compression ratio	28
3.6 Drying of Jaggery Cubes	29
3.6.1 Drying rate	29
3.7 Physico-Chemical Analysis of Jaggery Cubes Prepared Using Jaggery Cube Making Machine	30
3.7.1 Moisture content analysis	30
3.7.2 Dimensions	30
3.7.3 Weight	30
3.7.4 pH	30
3.7.5 Electrical conductivity	31
3.7.6 Total Soluble Solids (°Brix)	31
3.7.7 Color evaluation	32
3.7.8 Density	32
3.7.9 True volume	33
3.7.10 Textural analysis	33
3.7.11 Shattered index	33
3.7.12 Solubility	34

IV	RESULTS AND DISCUSSIONS	35-48
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4.1 Development of manually operated machine for making jaggery cubes using jaggery powder	35
4.1.1 Preliminary designing experiment result	35
4.1.2 Physico-chemical analysis of jaggery powder	35
4.1.2.1 Moisture content	35
4.1.2.2 Sieve analysis	36
4.1.2.3 pH	36
4.1.2.4 Electrical conductivity	36
4.1.2.5 Bulk density	36
4.1.2.6 True density	36
4.1.2.7 Porosity	36
4.1.2.8 Total soluble solids (°Brix)	36
4.1.2.9 Color evaluation	37
4.1.2.10 Solubility	36
4.1.3 Design principle and considerations	37
4.1.4 Fabrication of the manually operated jaggery cube making machine	37
4.2 Performance Evaluation of Manually Operated Machine for Making Jaggery Cubes Using Jaggery Powder	41
4.2.1 Production capacity	41
4.2.2 Production time component of the machine	41
4.2.3 Machine efficiency	42
4.2.4 Compression volume	42

4.2.5 Compressed density	42
4.2.6 Compression ratio	42
4.3 Drying of jaggery cubes	44
4.4 Physico-chemical analysis of jaggery cubes prepared from jaggery cube making machine	46
4.4.1 Moisture content	46
4.4.2 Dimensions	46
4.4.3 Weight	46
4.4.4 pH	46
4.4.5 Electrical conductivity	46
4.4.6 Total soluble solids (°Brix)	46
4.4.7 Color evaluation	47
4.4.8 Density	47
4.4.9 True volume	47
4.4.10 Textural analysis	47
4.4.11 Shattered index	47
4.4.12 Solubility	47
V SUMMARY AND CONCLUSION	49-51
REFERENCES	52-56
APPENDICES	57-58
APPENDIX – A	57
APPENDIX – B	58
RESUME	59

LIST OF TABLE

S. No	Title	Page No.
2.1	Nutritive compositions in different forms of jaggery	7
3.1	Description of preliminary experiment's samples	16
3.2	Specification of material used	24
4.1	Mean production time component of the machine	42
4.2	Physico-chemical properties of prepared jaggery powder and prepared jaggery cubes	48

LIST OF FIGURES

Figure No.	Title	Page No.
2.2	Process flow chart for manufacturing powder jaggery	10
3.1	Different views in 3D model of the jaggery cubes making machine	23
3.2	Orthographic views of the jaggery cubes making machine	23
3.3	Process flow diagram for making jaggery cube using jaggery cube making machine	27
4.1	Top view of manually operated jaggery cube making machine (in mm)	40
4.2	Side view of jaggery making machine (in mm)	41
4.3	Front view of jaggery cube making machine (in mm)	41
4.4	Moisture content vs time graph for drying of jaggery cubes	44
4.5	Variation in drying rate with drying time for different drying temperature	45

LIST OF PLATES

Plate No.	Title	Page No.
3.1	Jaggery powder sample	15
3.2	Jaggery powder samples for preliminary experiments	16
3.3	Wooden frame for making jaggery cubes	17
3.4	Filling jaggery powder inside frame	17
3.5	Compression of jaggery powder	17
3.6	Compressed jaggery powder	17
3.7	Prepared jaggery cubes samples	17
3.8	Jaggery cubes packed in aluminium foil	17
3.9	Sieving of the jaggery powder	18
3.10	Measuring pH and electrical conductivity of jaggery powder	19
3.11	Total soluble solids analysis	20
3.12	Analysis of color values of jaggery powder	21
3.13	Marking the rods for cutting	25
3.14	Cutting of the plate and rods	25
3.15	Drilling of the plate	26
3.16	Punching of the flat plate	26
3.17	Welding process during fabrication	26
3.18	Grinding of the plates and rods	26
3.19	Drying of jaggery cubes using hot air oven	29
3.20	Determination of color values of jaggery cubes	32

3.21	True volume analysis of jaggery cubes	32
3.22	Textural analysis of jaggery cubes	33
3.23	Solubility analysis of the jaggery cubes and jaggery powder	34
4.1	Model of the stand frame	35
4.2	Model of the jaggery cube moulding frame	38
4.3	Model of the collection and base plate	38
4.4	Model of the compression plate	38
4.5	Model of the tension rods	39
4.6	Model of a) Check nut b) Clamp c) Viser d) Bush e) Threaded rod with handle	39
4.7	Lebelled diagram of manually operated jaggery cube making machine	40
4.8	Filling jaggery powder inside moulding frame	43
4.9	Manual compaction of the jaggery powder	43
4.10	Full compression stage of the machine	43
4.11	Pulling out the sliding base plate	43
4.12	Pulling out the collecting plate	43
4.13	Jaggery cubes prepared from machine	43
4.14	(a) Dried jaggery cubes at 70°C using hot air oven	48
4.14	(b) Dried jaggery cubes at 80°C using hot air oven	48

LIST OF ABBREVIATION AND SYMBOLS

Abbreviation and Symbols	Description
%	Percent
ρ_b	Bulk density
ρ_t	True density
/	per
\pm	Plus-minus
$^{\circ}\text{C}$	Degree celsius
μ	Micro
3D	Three dimensional
Agril. Engg.	Agricultural Engineering
AICRP	All India Coordinated Research Projects
Atm.	Atmospheric
AOAC	Association of Official Agricultural Chemists
ASTM	American Society for Testing and Materials
B	Breadth
cm	Centimeter
cm³	Cubic centimeter
CoLk	Coimbatore Lucknow
CR	Color reader
db	Dry basis
<i>et al.</i>	And others
<i>etc.</i>	Et Cetra
FAE	Faculty of Agricultural Engineering
Fig.	Figure
g	Gram

G.I.	Galvanized iron
H	Height
h⁻¹	Per hour
hr	Hours
ICAR	Indian Council of Agricultural Research
IGKV	Indira Gandhi Krishi Vishwavidyalaya
IISR	Indian Institute of Sugarcane Research
K	Kelvin
kcal	Kilocalorie
kg	Kilogram
kgf	Kilogram force
kJ	Kilo joule
kPa	Kilopascal
L	Length
LCD	Liquid Crystal Display
m	Meter
M.S./m.s.	Mild steel
M.Tech.	Master of Technology
m³	Cubic meter
Min./min	Minute
MJ	Mega Joule
ml	Millilitre
mm	Millimeter
MT	Metric ton
N	Newton
No./no.	Number
P	Porosity

PET	Polyethylene Terephthalate
pH	Potential of hydrogen
RARS	Regional agricultural research station
Rh	Relative humidity
RS and JRS	Regional Sugarcane and Jaggery Research Station
sec	Second
T	Thickness
TSS	Total soluble solids
V	Volume
V_f	Final volume of cubes
V_i	Initial volume of cubes
vs	Versus
wb	Wet basis

THESIS ABSTRACT

Title of the Thesis : Development and performance evaluation of manually operated machine for making jaggery cubes using jaggery powder

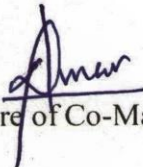
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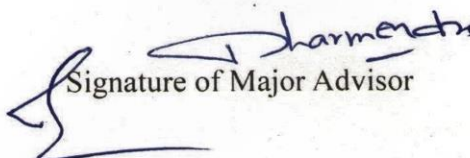
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ABSTRACT

Jaggery is the traditionally used Indian sweetener, also known as 'Medicinal sugar'. Jaggery powder is also popular, particularly among rural regions and the production of jaggery is the best entrepreneurship opportunity for the people. The demand for sugar cubes is increasing nowadays in the market. Jaggery powder may be used as a healthy alternative and replacement for sugar as its nutritional value is much higher than refined sugar. Under this situation, compressed jaggery cubes could be used in beverages and confectionary instead of sugar or artificial sweeteners.

The manually operated machine for making jaggery cubes using jaggery powder was developed. The machine make jaggery cubes and helps farmers for making a marketable product using the jaggery powder to increase income and their profit. The preliminary designing experiment was done using the graded jaggery powder of fine (less than 0.300 mm), medium (0.500-0.850 mm) and large (more than 0.850 mm) with various levels of moisture contents. The fine (less than 0.300 mm) jaggery powder having a moisture content of 7.00% was selected for the performance evaluation of the machine.

This manually operated jaggery cube machine having the dimension of 450 mm×300 mm×420 mm with rotating threaded handle of length 380 mm and cuboidal compartments on jaggery cube moulding frame having the dimension of 15 mm×15 mm× 45 mm was made using the mild steel. The machine consists of various parts i.e. stand frame, jaggery cube moulding frame, base plate, compression plate, tension rod, rotating handle, side handle. The production capacity of the machine was about 5.04 kg/hrs (tested with the jaggery powder). The machine produces an averagely of 0.120 kg or 20 jaggery cubes, each cubes weighing 6g in about 85 sec time frame. The efficiency of the machine for making jaggery cubes observed was 98.33% and an average value of the compression ratio, compressed volume, compressed density of the jaggery cubes was 2.825, 3.587 cm³ and 1.65 g/cm³ respectively.

The physicochemical properties of jaggery powder i.e. moisture content, Bulk density, True density, pH, electrical conductivity, total soluble solids (°Brix) and solubility were found 7.00%, 812 kg/m³, 1046 kg/m³, 2.310 µs/cm, 6.178, 11.9 and 98.67% respectively. The color values L, a, b of jaggery powder was found 33.8, 1.2, 5.2 respectively. The drying time of the prepared jaggery cubes, dried using a hot air oven up to less than 2% moisture content at an air temperature of 70°C and 80°C was found 10 hrs and 8 hrs respectively.

The jaggery cubes dried at 80° C using the hot air oven was selected for the physico-chemical analysis i.e moisture content, True volume, density, pH, electrical conductivity, total soluble solids (°Brix), shattered resistance, solubility,

hardness and resilience were found 1.92-1.99%, 0.00000034 m³, 1.60 g/cm³, 5.714, 2.686 μs/cm, 11.8, 98.50%, 400.66- 417.02 N and 0.80-0.90 respectively. The color values L, a, b of jaggery powder was found 25.3, 0.5, 7.6 respectively. The length, breadth and height were found 15±0.1 mm, 15±0.1 mm and 15±3 mm respectively.

The jaggery cubes were of good quality and used as a sweetener in the confectionary and beverages. The manually operated jaggery cube making machine was found low-cost, easy to fabricate, easy to operate for making jaggery cubes and was useful for the domestic and small scale industries.

Keywords: Jaggery powder, jaggery cubes, marketable products, manually operated jaggery cube making machine, confectionary.

शोध सारांश

शोध शीर्षक	: गुड़ पाउडर का उपयोग करके गुड़ क्यूब्स बनाने के लिए हस्त-चालित मशीन का विकास और प्रदर्शन मूल्यांकन
छात्र का पूरा नाम	: शैलेश कुमार मरकाम
प्रमुख विषय	: कृषि प्रसंस्करण और खाद्य अभियांत्रिकी
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दिलीप

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विभाग के प्रमुख के हस्ताक्षर

सारांश

गुड़ पारंपरिक रूप से इस्तेमाल किया जाने वाला भारतीय स्वीटनर है, जिसे 'औषधीय चीनी' के रूप में भी जाना जाता है। खासकर ग्रामीण क्षेत्रों में, गुड़ पाउडर भी लोकप्रिय है और गुड़ के उत्पादन में लोगों के लिए सबसे अच्छा उद्यमिता के अवसर है। बाजार में आजकल चीनी के क्यूब्स की मांग बढ़ रही है। गुड़ के पाउडर को चीनी के स्थान पर एक स्वस्थ विकल्प के रूप में इस्तेमाल किया जा सकता है क्योंकि इसका पोषण मूल्य परिष्कृत चीनी की तुलना में बहुत अधिक है। इस स्थिति में, चीनी या कृत्रिम मिठास के जगह पेय और मिष्ठान में संपीड़ित गुड़ के क्यूब्स का उपयोग किया जा सकता है।

गुड़ के पाउडर का उपयोग करके गुड़ के क्यूब्स बनाने के लिए हस्त-चालित मशीन विकसित की गई थी। मशीन गुड़ के क्यूब्स बनाकर, किसानों की आय व उनके लाभ को बढ़ाने के लिए गुड़ के पाउडर का उपयोग करके एक विपणन योग्य उत्पाद बनाने में मदद करती है। प्रारंभिक प्रयोग में विभिन्न स्तरों की नमी वाले महीन (0.300 मिमी से कम), मध्यम (0.500-0.850 मिमी) और बड़े (0.850 मिमी से अधिक) वर्गीकृत गुड़ पाउडर का उपयोग करके किया गया था। प्रारंभिक प्रयोग के अनुसार मशीन के प्रदर्शन मूल्यांकन के लिए 7.00% की नमी वाले महीन (0.300 मिमी से कम) गुड़ पाउडर का चयन किया गया था। गुड़ के क्यूब्स बनाने के लिए मशीन की दक्षता 98.33% प्राप्त हुआ और गुड़ के क्यूब्स के संपीड़न अनुपात, मात्रा, घनत्व का औसत 2.825, 3.587 cm³ और 1.65 g/cm³ था।

यह मशीन 450 मिमी x300 मिमी x420 मिमी के आयाम वाली, 380 मिमी की ऊँचाई के थ्रेडेड हैंडल और 15मिमी x15 मिमीx15 मिमी के आयाम वाले गुड़ क्यूब मोल्डिंग फ्रेम पर आयातफलकीय डिब्बों के साथ माइल्ड स्टील का उपयोग करके बनाई गई थी। मशीन में विभिन्न भाग हैं जैसे स्टैंड फ्रेम, गुड़ क्यूब फ्रेम, बेस प्लेट, कम्प्रेसन प्लेट, टेंशन रॉड, रोटेटिंग हैंडल, साइड हैंडल। मशीन की उत्पादन क्षमता लगभग 5.04 किग्रा./घंटा (गुड़ पाउडर से परीक्षित) थी। मशीन औसतन 0.120 kg या 20 गुड़ के क्यूब्स का उत्पादन करती है, प्रत्येक क्यूब का वजन लगभग 85 सेकंड की समय सीमा में 6 ग्राम होता है।

गुड़ पाउडर के भौतिक रासायनिक गुण यानी नमी की मात्रा, थोक घनत्व (Bulk density), सही घनत्व (True density), पीएच (pH), कुल घुलनशील ठोस (°Brix) और घुलनशीलता क्रमशः 7.00%, 812 kg/m³, 1127 kg/m³, 6.128, 2.310 µs/cm, 11.9 और 98.67% प्राप्त हुआ। तैयार गुड़ पाउडर के रंग मान (color values) L, a, b क्रमशः 33.8, 1.2, 5.2 पाया गया। तैयार गुड़ के क्यूब्स को सुखाने, गर्म हवा के ओवन (Hot air oven) का उपयोग करके 70°C, 80°C के हवा के तापमान पर 2% से कम नमी की मात्रा तक सुखाने में क्रमशः 10 घंटे और 8 घंटे का समय प्राप्त हुआ।

गर्म हवा के ओवन (Hot air oven) का उपयोग करके 80°C पर सुखाए गए गुड़ के क्यूब्स को भौतिक-रासायनिक विश्लेषण यानी नमी की मात्रा, घनत्व, पीएच (pH), विद्युत चालकता, कुल घुलनशील ठोस (°Brix), बिखर प्रतिरोध (Scattered resistance), घुलनशीलता (Solubility) कठोरता और तन्यकता (Resilience) क्रमशः 1.92-1.99%, 1.60

g/cm^3 , 5.703, 2.686 $\mu\text{s/cm}$, 11.8, 4.020, 98.50%, 400.66-417.02 N और 0.80-0.90 प्राप्त हुआ। तैयार गुड़ के क्यूब्स का रंग मान (Color values) L, a, b क्रमशः 25.3, 0.5, 7.6 पाया गया। लंबाई, चौड़ाई और ऊंचाई क्रमशः 15 ± 0.1 मिमी, 15 ± 0.1 मिमी, 15 ± 3 मिमी प्राप्त हुआ।

गुड़ के क्यूब्स अच्छी गुणवत्ता का प्राप्त हुआ और गुड़ के क्यूब्स बनाने के लिए हस्त-चालित मशीन कम लागत वाली, बनाने में आसान, गुड़ के क्यूब्स बनाने के लिए संचालित करने में आसान और घरेलू और लघु उद्योगों के लिए उपयोगी पाया गया।

कीवर्ड - गुड़ पाउडर, गुड़ क्यूब्स, विपणन योग्य उत्पाद, गुड़ के क्यूब्स बनाने के लिए

हस्त-चालित मशीन, मिष्ठान।

CHAPTER – I INTRODUCTION

Sugarcane (*Saccharum officinarum*) is a major cash crop in India that belongs to the family *Gramineae*. The Sanskrit word "SARKARA", from which the name "SACCHARUM" appears to have been derived, also indicates that sugarcane knowledge in India is ancient (Lakshmikantham, 1983). In the financial year 2019, the yield of sugarcane was estimated at approximately 78 thousand kilograms per hectare of which 53 percent has been processed into white sugar, 36 percent into jaggery and khandsari, 3% has been consumed as cane juice and 8% being as seed cane in India (Statista, 2020).

According to studies, a sugarcane stalk comprises 14 percent sugar, while a sugar beet stalk contains 16 percent sugar. Sugar from sugarcane and sugar beet has a unique taste, colour, and fragrance, as well as a distinct behaviour (Flourish, 2018). A refinery converts raw sugar from a light brown raw sugar with a purity of nearly 98.5 percent to an almost pure (>98 percent) white sugar for sale to consumers (Rein, 2009).

Jaggery is a sweetener that was used in India since ancient times. It's a non-centrifugal, unrefined sugar that's popular in Africa, Asia, Caribbean and the Latin America. It's a concentrated product made from dates, cane juice, or palm sap which doesn't separate the molasses and crystals. Its colour ranges from golden brown to dark brown, and the high molasses content is attributed to its distinct flavour and aroma. India is the world's largest jaggery producer and consumer (Nath *et al.*, 2015).

Jaggery can contain up to 50 percent sucrose, up to 20% invert sugars, up to 20% moisture content, with the remaining made up of various insoluble materials such ash, proteins, and bagasse fines. It is abundant in vital minerals (*viz.*, Calcium-40-100 mg, Magnesium-70-90 mg, Potassium-1056 mg, Sodium-19-30 mg, Phosphorus-20-90 mg, Iron-10-13 mg, Copper-0.1-0.9 mg, Manganese-0.2-0.5 mg, Chloride-5.3 mg and Zinc-0.2- 0.4 mg per 100 g of jaggery). It contains all the vitamins (*viz.*, Vitamin A-3.8 mg, Vitamin B1-0.01 mg, Vitamin B2- 0.06 mg,

Vitamin B5-0.01 mg, Vitamin B6-0.01 mg, Vitamin C-7.00 mg, Vitamin D2-6.50 mg, Vitamin E-111.30 mg, Vitamin PP-7.00 mg), and protein (280 mg per 100 gram of jaggery (Shrivastav *et.al*, 2016).

Minerals like magnesium found in jaggery help to improve the human nervous system, relax body muscles, relieve tiredness, and protect blood vessels. Along with selenium, it also functions as an antioxidant, scavenging free radicals from our bodies. Jaggery contains potassium and a small amount of sodium, which aids in the maintenance of acid balance in body cells, as well as combating acids and acetone and regulating blood pressure. It is considered a rich source of iron, which aids in the prevention of anemia and, due to its anti-allergic qualities, it aids in the relief of stress and the treatment of asthma (Singh *et. al.*, 2011). It cleanses the lungs, stomach, intestines, oesophagus, and respiratory systems (Nath *et al.*, 2015).

In India, solid jaggery accounts for around 80% of jaggery production, while liquid and granular or powder jaggery accounts for the remaining 20%. For preparing solid jaggery (cube shape), filtered cane juice was pumped into open pans kept on a triple pan furnace and heated with the bagasse as fuel. The juice was clarified with herbal clarificant (deola extract @ 45 g per 100 kg cane juice), to make light-colored jaggery by eliminating impurities in suspension, colloidal and coloring compounds by accumulation. The juice was then boiled and concentrated to make jaggery in the desired shape and size (Singh *et al.*, 2013).

Liquid jaggery is another sweetener, which is made by concentrating filtered sugarcane juice by evaporating the water until the temperature reaches 103-106°C. Liquid jaggery is a semi-liquid syrup that serves as a transitional product. Like solid jaggery, it has excellent nutritional and medicinal properties. 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).

Jaggery powder is also very popular, especially in rural areas. The quality crystalline jaggery powder is made by adjusting the pH of the juice to 6.0–6.2 by

adding lime solution, then boiling the juice and clarifying it simultaneously with deola mucilage (*H. ficulneus*). Powder jaggery's striking point temperature ranges around 120°C and 122°C (Rao *et al.*, 2007, Singh *et al.*, 2011). The heated mass is cooled in the cooling pan with thorough puddling and then left for crystallising and slurry formation for 5 to 10 min without stirring. The semi-cooled mass containing seed crystals is then transferred to an aluminium tray and severe shearing action with wooden or stainless steel scrappers is used to transform the mass into granules. To obtain uniform-sized granules, the product is dried to a moisture level of 1-2% and sieved through a 3 mm size sieve. It's then packed into PET bottles and moisture-proof polyethylene-polyester laminates.

The sugar in the form of cubes is available in the market and has a high-demanding product for star hotels, flights, family parties and meetings. Sugar crystals are wetted and pressed to make the sugar cubes. To avoid cube conglutination, these compacted sugar crystals are dehydrated. For hydrating the sugar cubes, the hot air oven method is commonly used (Skočilas *et al.*, 2016). On the other side demand for jaggery powder and small cubes, as a sweetener is also increasing nowadays in domestic as well on the international market. Granular and cubic shape jaggery with its low moisture level offers numerous advantages like extended storage life, easy handling, handy packaging and distribution (Pawar *et al.*, 2017). When compared to sugar, jaggery is a healthier alternative. It contains 65–85 percent sucrose, compared to 99.5% sucrose in sugar. Sugar has a mineral concentration of only 0.05%, but jaggery has a mineral concentration of 0.6 to 1.0%. The mineral content of jaggery powder is high (0.6–1%), with 9 mg calcium, 4 mg phosphorous, and 12 mg iron per 100 g (Singh *et al.* 1978). Under this situation, compressed jaggery cubes made using jaggery powder or granular jaggery may be used as replacement for sugar as its nutritional value is much higher than that of refined sugar, thus making it a healthier alternative of sweetener in beverages.

To overcome such problem as mentioned above, manually operated machine was developed for making the jaggery cubes and performance evaluation was done using the jaggery powder. Physico-chemical analysis of jaggery cubes

was also analysed. Based on the above facts the present research entitled, **“Development and performance evaluation of manually operated machine for making jaggery cubes using jaggery powder”** had been carried out with the following objectives.

- 1) Development of manually operated machine for making jaggery cubes using jaggery powder.
- 2) Performance evaluation of manually operated machine for making jaggery cubes using jaggery powder.
- 3) Physico-chemical analysis of jaggery cubes prepared from manually operated machine for making jaggery cubes using jaggery powder.

CHAPTER-II

REVIEW OF LITERATURE

This chapter gives a brief account of available literature related to the proposed area of research under different heads and sub-heads. Many researchers have been carried out various experiments related to the processing and properties of jaggery powder reviewed thoroughly. The developments of machines, nutritional and medicinal values of the jaggery have also been briefed.

2.1 Status of jaggery production in India

Said and Pradhan (2013) reviewed that sugarcane is primarily processed into three products: sugar, jaggery, and khandsari with jaggery being a traditional Indian sweetener. Maharashtra, Andhra Pradesh, Haryana, Karnataka, Uttar Pradesh, Punjab and Tamil Nadu were among those states where the jaggery industry flourished. Jaggery and Khandsari were processed with over 37.2% of the total sugarcane output. Jaggery processing and preservation were being worked on by several institutes and scientists. Many of them had invented innovative processing technologies, equipment for jaggery manufacturing, storage methods in jaggery preservation, and value-added goods to complement jaggery. The Lucknow-based IISR had created various processing equipment (pans) and standardised the production process for hygienic jaggery making. Jaggery is becoming more popular around the world because to its nutritional and medicinal value, as well as its potential for export.

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 the 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.

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

Kumbhar (2016) conducted the survey at the 25 random units of gur manufacturing of the major cluster of Kolhapur district of Maharashtra. He reported that the gur profile of Kolhapur district was of good specialty with golden color, chemical-free, pure and hygienically produced. Further, he also mentioned that the health benefits of Kolhapuri gur as it is rich in vitamins and minerals. It is also useful for the strengthening of the nervous system, relaxation of muscle and antioxidant properties 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 gur production is profitable with an efficiency ratio of 1.33 and a profitability ratio of 0.338.

Pawar *et al.* (2017) reported that jaggery was a naturally made sweet prepared by the concentration of cane juice by using clarification process for removing the unwanted particles and was uniformly heated inside the open pan. It was getting affected by various factors from cultivation practices of cane to storage and processing. The utilization of sugarcane in the production process of the khandsari and jaggery was considerably declined from 37.20 during year 2008-2009 to about 16.90 in 2011-2012. This indicates the need for innovations and knowledge for producing the good quality jaggery and change the present framework. But there were some research workers and institutes i.e RARS, Anakapalle, IISR, Lucknow, RS and JRS, Kolhapur, had presented some research reports for technological developments in jaggery processing, storage and packaging.

2.2 Nutritional and medicinal importance of jaggery

Asokan *et al.* (2007) mentioned that jaggery comprised of 60 -85% of sucrose, 5-15% glucose and fructose together with 0.4% of protein, fat of 0.1% and 0.6-1.0%

mineral, calcium of 8 mg, phosphorus of 4 mg, iron of 11.4 mg per 100 g of the jaggery. 100 g of jaggery provides 383 kcal of the energy. It also contains some amount of vitamins, antioxidants and amino acid.

Table 2.1: Nutritive compositions in different forms of jaggery

Composition (per 100 g)	Solid jaggery	Liquid Jaggery	Powder jaggery
Water, g	3-10	30-35	1-2
Sucrose, g	65-85	40-60	80-90
Reducing ,g	9-15	15-25	5-9
Fat , g	0.1	0.1	0.1
Protines, g	0.4	0.5	0.4
Total minerals, g	0.6-1.0	0.75	0.6-1.0
Phosphorous, g	4	3	4
Calcium, g	8.0	300	9.0
Iron, g	11.4	8.5-11	12
Calorific value, kcal	383	300	383

Source: Rao *et al.* (2007), Jaggery- A traditional Indian sweetener

Kumar *et al.* (2015) reported that jaggery was also known as 'medicinal sugar' and it was nutritionally comparable to honey. It had predominance over sugar as it comprises 80-85% sucrose and 5-15 percent reducing sugars while also providing critical elements such as proteins, lipids, vitamins, minerals, and energy. Several Ayurvedic remedies were made with jaggery.

Rajesh *et al.* (2016) reviewed that jaggery was popularly used in raw drug which further used in ayurvedic medicines and curative purposes. They found that it was generally prepared from sugarcane and also from palm, coconut, date etc. Jaggery is widely used in pharmaceuticals in the preparation of Ayurvedic dosage forms such as avaleha, vataka, guda, Arishta, Asava, gudika etc..There are many forms of jaggery available in the market. The mineral content of jaggery was 60

times more than the refined sugar. 1 tablespoon of the jaggery will contain up to potassium, magnesium, calcium, phosphorus and iron of 48 mg, 8 mg, 4-5 mg, 2-3 mg and 0.5 mg and some quantity of zinc, copper, thiamin, riboflavin, and niacin. The nutritional values of white table sugar seemed to all was approximately zero.

Rao et al. (2007) mentioned that taking jaggery in diet may protect from several incidences of cancer in lungs and atmospheric pollution-related toxicity. The jaggery is rich in valuable vitamins and minerals. The magnesium provides strength to the nervous system, relaxes muscles and mitigate fatigue and also supervise blood vessels. The potassium and low amount of sodium, in jaggery maintains body cell's acid balance, and also dispute acids, acetone and blod pressure control. Iron cures anemia and also helpful for relieving tension and asthma control, as jaggery had anti-allergic properties. The jaggery is protective food for persons working in a smoky and dusty. Therefore the jaggery may help to breathe easier and protects from pollution-related problems. A moderate amount of zinc, phosphorous and calcium will helps in maintaining optimum health and purifies the blood, prevents rheumatic affection and biling disorder and in curing jaundice.

2.3 The production process techniques of different types of jaggery

(i) Solid jaggery

Nath et al. (2015) studied advances in value-addition of jaggery based products. He discussed the production of solid jaggery. The sugarcane juice was filtered and was pumped into the open pans kept on triple pan furnace, and baggase used as a fuel. The sugarcane juice clarification was done using the herbal clarificant (extract of deola @ 45 g per 100 kg of juice) for making light colored jaggery by removing suspension's impurities, colloidal and coloring compounds using the accumulation process. Desired shape and size obtained by boiling and concentrating sugarcane juice.

(ii) Liquid jaggery

Patil, et al. (1996) stated the advanced production of liquid jaggery. After extracting the juice from crushers, cane juice was stored in a settling tank for some

time, in which potassium alum crystal stones are dipped for 30 sec for quick sedimentation of soil or foreign particles etc. Then, the cleared juice transferred to boiling pan on furnace for adjustment of pH to desired level i.e. between 5.8-6.0 by adding lime and after some time for clarification *deola mucilage* and phosphoric acid were added. The liquid jaggery had a striking point temperature of 105°C-106°C to have a good quality product with minimum microbes growth and crystallization. The addition of citric acid (0.04%) minimizations of the crystallization process with increased glucose or fructose in liquid jaggery and also improves color. Excessive use of citric acid leads to an acidic taste while preventing crystallization when less of it. Liquid jaggery composed of water: 30 - 35 %, sucrose: 40 -60%, calcium: 0.3 %, invert sugar: 15-25%, iron: 8.5-11 mg per 100 g jaggery, phosphorous 3 mg per 100 g of jaggery, protein 0.10 mg per 100 g of jaggery.

(iii) Powder jaggery

Nath *et al.* (2015) stated that the granular jaggery preparation process was the same up to concentration process in solid jaggery production process. The rubbing of the concentration slurry was done using the wood scraper, for grains formation. Then the granular jaggery was cooled and sieved. The granules size less than 3 mm are found suitable for preparing the quality granular jaggery. The pH raised by adding the lime in juice, up to 6.0 to 6.2 and striking point temperature of 120°C was found to enhance granular jaggery quality having high sucrose content of 88.6%, low moisture of 1.65% having good color, crystallinity and friability. Jaggery in the granular form (sieved to about 3 mm), sun dried and moisture level reduced below 2%, and packed inside polyethylene polyester bag or bottles, can be stored for an extended time (more than two years). Color of powder jaggery ranged from golden yellow to golden brown dark brown like the dark chocolaty color.

2.4 Properties of sugar and sugar cubes

Choong *et al.* (2016) Sugars from *Arenga pinnata* and *Saccharum officinarum* were studied for their physico-chemical properties, antioxidant activity, and volatile compound. The maximum L* value was found in granulated sugar,

whereas the lowest L^* value was found in powder jaggery ($p < 0.05$). The solubility varied between 99.18 and 99.57%. Aren sugar had the maximum moisture level (4.11%), crude fat (0.11%), crude fibre (0.02%), and reducing sugar (9.31%). Refined cane sugar has a considerable quantity of carbohydrate (99.95%), total soluble solid (90.00 °Brix), and water activity (0.55 a_w) as a control. pH ranged from 4.14 to 6.65 in all of the samples.

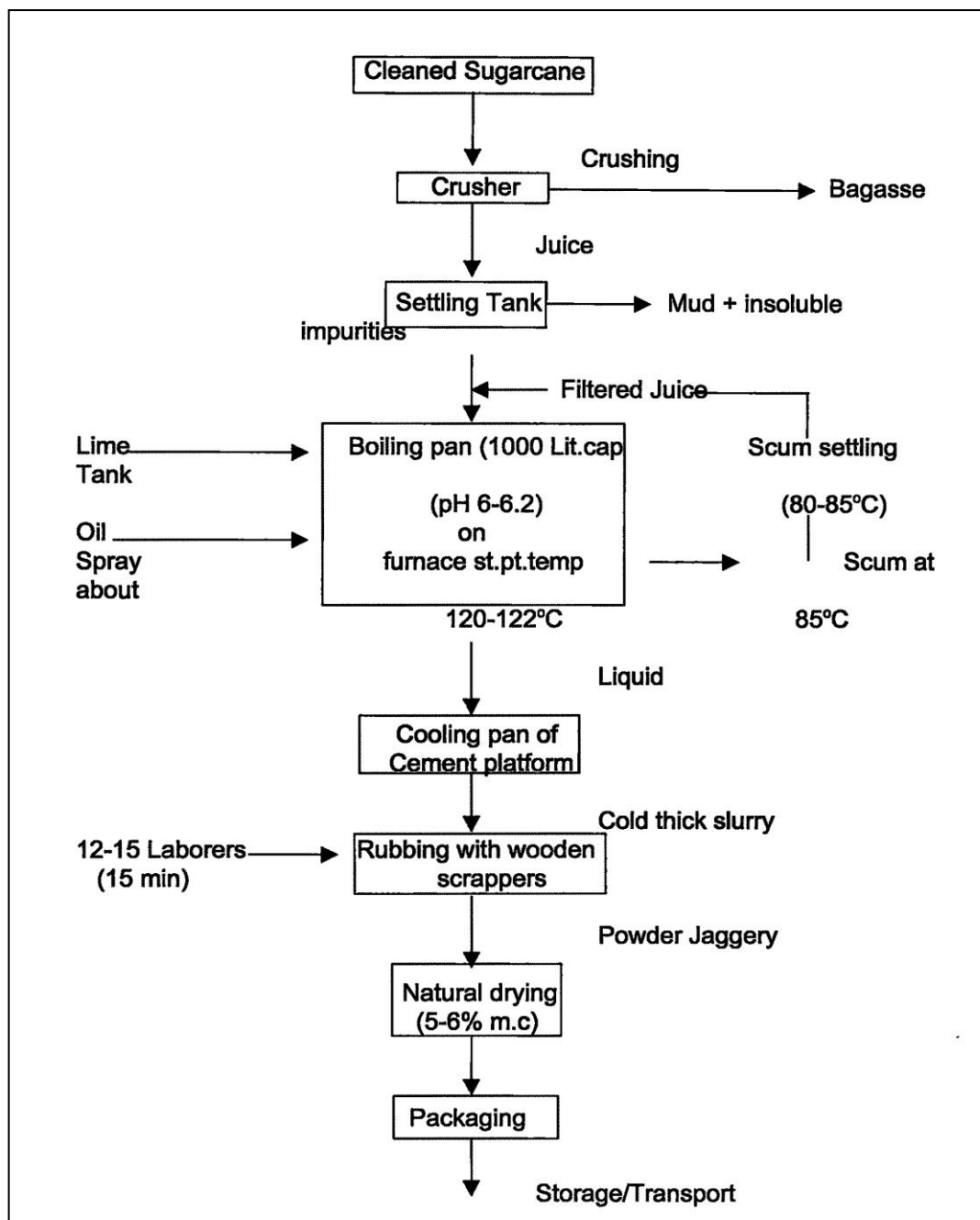


Fig.2.2: Process flow chart for manufacturing powder jaggery

Source: Patil *et al.* (1995)

2.5 Engineering properties related to jaggery and jaggery powder

Rao *et al.* (2008) studied the moisture contents effect on the thermal and physical properties of granulated jaggery made from palmyra palm, sugarcane, and date palm was analyzed. Thermal conductivity and diffusivity were evaluated using transient heat-transfer methods using a line-heat source and specific heat computed using supplementary data on the sample's bulk density. Thermal conductivity, specific heat, diffusivity and bulk density was found to vary from 0.08 to 0.39 Wm⁻¹ K⁻¹, 1.19 to 2.97 kJ kg⁻¹ K⁻¹, 0.10 to 0.13 ×10⁻⁶ m² s⁻¹, and 510 to 1310 kg m⁻³ respectively, for moisture ranging from 2.0 to 14.3 (%db), 30°C as average temperature.

Guerra and Mujika (2010) studied physico-chemical analysis of two commercial brands of artisanal granulated panela, and they found the higher variation in parameters i.e. moisture (1.66-4.36 g/ 100 g), reducing sugars (4.58-11.48 g/ 100 g), a_w (0.51-0.69), pH (5.58-6.90) and colour. The most abundant mineral found was Potassium (229.52-1027.18 mg / 100 g).

Unde *et al.* (2011) analyzed the effects on storability and packaging materials of the different particle sizes of jaggery powder based on chemical composition changes and organoleptic characteristics. Powder jaggery prepared with 3 different grades i.e. coarse (0.500-0.708 mm), medium (0.351- 0.420 mm) and fine (0.211- 0.296 mm) and was packed in a 100 gauge polyethylene bag. The samples were stored at room temperature for 6 months. They found that the changes in chemical composition was lower for coarse powder jaggery. The coarse powder jaggery with a particle sized ranging from 0.500- 0.708 mm found more suitable among all other sized powder jaggery after a six months storage period in terms of its chemical and organoleptic characteristics.

Nighita and Sudagar (2017) studied the important engineering properties of palmyrah palm jaggery. Three different grades of jaggery were obtained and classified based on the fineness modulus values. The values range from 5.5-6.5 (coarse), 4.5-6.5 (medium), 4.5-6.5 (fine) respectively. The result was revealed that the mean values of size, true volume, true density, moisture content, porosity, bulk

density, coefficient of frictions against various surfaces was found to vary from 4.11 ± 0.69 mm in height, 93.0 ± 0.49 mm diameter, $0.00014 \pm 1.2 \text{ m}^3$, $1344.65 \pm 2.4 \text{ kg/m}^3$ respectively. While the moisture content on different sizes of palmyrah palm jaggery was found to be in the range of coarse (3.23), medium (3.1) and fine (2.9). Bulk density and porosity of jaggery before and after disintegration obtained 687.08 ± 12 , $765.85 \pm 31 \text{ kg/m}^3$ and 48.83 ± 2.3 , 42.77 ± 9.3 respectively.

2.6 Value addition in jaggery

Anwar *et al.* (2011) developed a jaggery powder enriched with vitamin C by adding through a natural source i.e. aonla fruit's cutted into pieces and was found best when dried up to 10 percent moisture content, followed by fine and grated powder samples formed using amla, as shown by the sensory analysis.

Chand *et al.* (2011) studied the various characteristics of the prepared jaggery chocolate under various storage situations. During the period of storage from 15 to 60 days the Moisture level, optical density, hardness and sensory property analysis of the jaggery chocolates stored were evaluated. They found that moisture level, hardness and optical density of chocolates varied from 6.09 to 8.42%, 4.29 kgf to 11.58 kgf and 0.12 to 0.529 respectively.

Kulkarni *et al.* (2013) studied the production of chocolate nuggets using powder jaggery, containing various benefits of minerals, vitamins, protein and also uses sugar compared to sugar. Formulation of Chocolate nugget using cocoa powder, jaggery powder, cocoa butter, spices and nuts.

Kumar (2015) stated that the nutritional and medicinal quality and taste of jaggery can be effectively enhanced by adding dried shredded aonla, dried ginger (sonth), black pepper (kali-march), turmeric (Haladi) etc. It was also used in various baked products i.e biscuits, chocolates, cakes, bread, pastries, gaga, chikki, rolls etc.

Lamdande *et al.* (2018) prepared muffins by utilizing jaggery instead of sugar replacing 84% sugar with jaggery percentage of 42, 63 and 84. Eggs with various levels i.e 42, 63 and 84 % were tested for preparing muffins from jaggery.

They found that muffins made using 84% each of jaggery and eggs had acceptable quality characteristics.

Mahalaxmi and Hemalatha (2019) formulated muffins by replacing sugar to organic jaggery and non-organic jaggery with various formulations and nutritional analysis of accepted and selected muffins. In the little millet jaggery-based muffins, 100% non-organic jaggery, and 120% organic jaggery was selected and accepted.

2.7 Projects related to the jaggery cube, design and development of briquetting machine

Anonymous (2017) Process for making Granular jaggery cubes to use as a sweetener in beverages was developed by AICRP on post-harvest Engineering Technology, RARS, Annakapalle. The compressed jaggery cubes contain sucrose, glucose, fructose, iron, calcium, potassium including Vitamin A and B. Compressed jaggery cubes weighing 300 mg, Dimensions i.e. diameter: 9.45 mm and thickness: 3.75 mm using granular jaggery and edible binder (maltodextrin) was developed.

Osarenmwinda and Ihenyen (2012) designed and fabricated a manual briquetting machine having the capacity of 10 tonnes by using the agro-waste with the use of materials available locally. The main parts of the machine which were made up of frame, chamber for compaction and base plate. The compaction chamber contained of twenty molding dies with each having a piston, transmission rod, and ejector. The compaction force and pressure were found at 215.3 N and 17.5 kN/m² respectively. The machine will be applicable for small- scale and medium-scale briquette manufacturers.

Obi et al. (2013) deal with the design and construction of a commercially used biomass briquetting machine that was acceptable for using in the rural areas and for performance evaluation saw dust was used. Using cassava starch as the binding agent, they examined the combustion and physical parameters of the briquette at different ratios of biomass-binder i.e. 100:15, 100:25, 100:35, and 100:45. The optimal biomass-binder ratio based on compressed density was found to be 100:25, with a compressed density of 0.7269 g/cm³ and the value of heating of 27.17 MJ/kg, whereas the optimum level of blend ratio based upon heating value

was found to be 100:35, with having compressed density of 0.7028 g/cm^3 . The machine had the production capacity of 43 kg/hrs.

Taram *et al.* (2017) did evaluation of the performance of hydraulic operated tamarind briquetting machine at various levels of moisture of tamarind pulp and the application of constant pressure at each stroke. The working of the prototype was found satisfactory as per the test resulted. The average briquette density varied from 0.94 to 1.07 g/cm^3 . They found that the pulp of tamarind, with a moisture level of 18.14-26.70% (wb) found acceptable for making briquettes. They found the final density (1.03 & 1.14 g/cm^3) for 500 and 1000 g/cm^3 of producing briquettes at a constant level pressure of 44057 kPa at every stroke. The prototype machine has the capacity of 45 briquettes/hrs for 500 g briquettes and 35 briquettes/hour for 1 kg briquettes. For briquettes of 1kg, the breakeven point predicted to be 225 briquettes per year, and for 500 g briquettes, 392 briquettes per year. For 1 kg briquettes, the payback period is predicted to be 0.31 years, for 500 g briquettes, it is estimated to be 0.41 year.

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 the determination of different parameters, equipment and instruments used along with their specifications. The entire chapter is divided into 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 Material

Sugarcane variety CoLk 94184 (Birendra), an commonly grown, early maturing sugarcane variety released by ICAR-IISR, Lucknow used for the preparation of jaggery powder by a standard method as shown in flow chart of Fig. 2.2 (Patil, *et al.*, 1994) at jaggery unit and used for the study.



Plate 3.1: Jaggery powder sample

Other materials

Strainer, muslin cloth, packaging bottle, test tube stand, distilled water jar, hand gloves, head cover, polyethene, apron, measuring cylinder, funnel, volumetric flask, beaker, petri plates, test tubes, electronic pipette, spreader etc.

3.3 Development of Manually Operated Machine for Making Jaggery Cubes Using Jaggery Powder

3.3.1 Preliminary experimental procedure for designing

The jaggery powder prepared as discussed in section 3.2 was dried and this jaggery powder was sieved into three grades of fine (<0.300 mm), medium (0.300-0.850 mm), coarse (0.850 mm<) powders (Table 3.1). Various quantity (5g, 6g, 7g) and moisture content ($5\pm 0.5\%$, $7\pm 0.5\%$, $9\pm 0.5\%$) of graded jaggery powder samples (Plate 3.2) were taken and filled inside compartments of the wooden frame, compressed manually using the press rod for preparing the jaggery cubes (Plate 3.3-3.8) and also the quantity of jaggery powder, dimension of the frame, size and various parameters of cubes were analyzed for using this data in the development and fabrication of the manually operated machine for making jaggery cubes using jaggery powder.

Table 3.1: Description of preliminary experiment's samples

S.No.	Samples	Powder sizes Descriptions	Sieve sizes
1	T ₁ (Fine powder)	less than 0.300 mm	ASTM 50
2	T ₂ (Medium powder)	between 0.300 -0.850 mm	ASTM 50, ASTM 20
3	T ₃ (Coarse powder)	more than 0.850 mm	ASTM 20



Plate 3.2: Jaggery powder samples for preliminary experiments

Data evaluated

- i) Selection of jaggery powder sample, size and moisture content of jaggery powder for the jaggery cube preparation.
- ii) Suitable quantity and height of jaggery powder column inside the frame.
- iii) Suitable dimensions of jaggery cube moulding frame and compartments formed.

Jaggery cube preparation during preliminary designing experiment

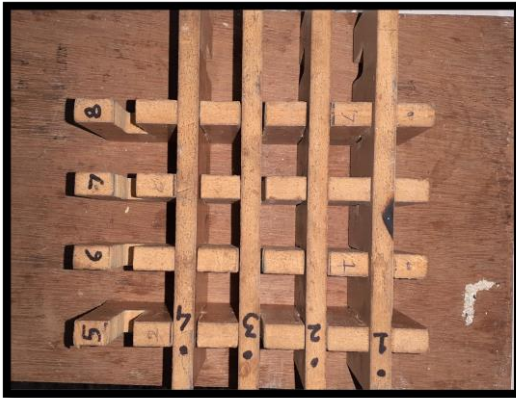


Plate 3.3: Wooden frame for making jaggery cubes



Plate 3.4: Filling jaggery powder inside frame



Plate 3.5: Compression of jaggery powder



Plate 3.6: Compressed jaggery powder



Plate 3.7: Prepared jaggery cubes samples



Plate 3.8: Jaggery cubes packed in aluminium foil

3.3.2 Physico-chemical analysis of jaggery powder

3.3.2.1 Moisture content analysis

The moisture content of jaggery powder was determined following the procedure reported by AOAC (1990) by using the oven method. Approximately 1 gram of jaggery powder was dried at 105°C for 4 hrs. Moisture content was calculated based on the weight difference before and after the drying procedure.

$$\text{Moisture content (\%)} = \frac{\text{Initial weight} - \text{Weight of dry sample}}{\text{Weight of dry sample}} \quad (3.1)$$

3.3.2.2 Sieve analysis

The size of the jaggery powder was determined following the method described by Nighitha and Sudagar (2020) using a sieving pan. The jaggery powder was taken for sieve analysis to separate the different sizes of jaggery powder. The weight of the jaggery powder retained in each sieve was noted. Different sizes of jaggery powder (fine, medium and coarse) were obtained. The average maximum size of the jaggery powder was determined based on the sieve analysis. During the test, the feed rate of jaggery was kept constant.



Plate 3.9: Sieving of the jaggery powder

3.3.2.3 pH

pH was determined by following the method described by Baboo and Anwar (1995) using Hanna pH and conductivity meter. The 13 g of jaggery powder sample was taken in a beaker and dipped in 100 ml water and 0.5 normality solution was prepared. The digital pH meter electrode was dipped inside the beaker and the reading for pH was noted down.

3.3.2.4 Electrical conductivity

Electrical conductivity was determined by following the method described by Baboo and Anwar (1995) using Hanna pH and conductivity meter. Jaggery powder sample was taken in a beaker, filled almost completely. The conductivity probe was dipped into the solution up to the mark. The conductivity reading that appeared on the screen was noted in $\mu\text{S}/\text{cm}$.

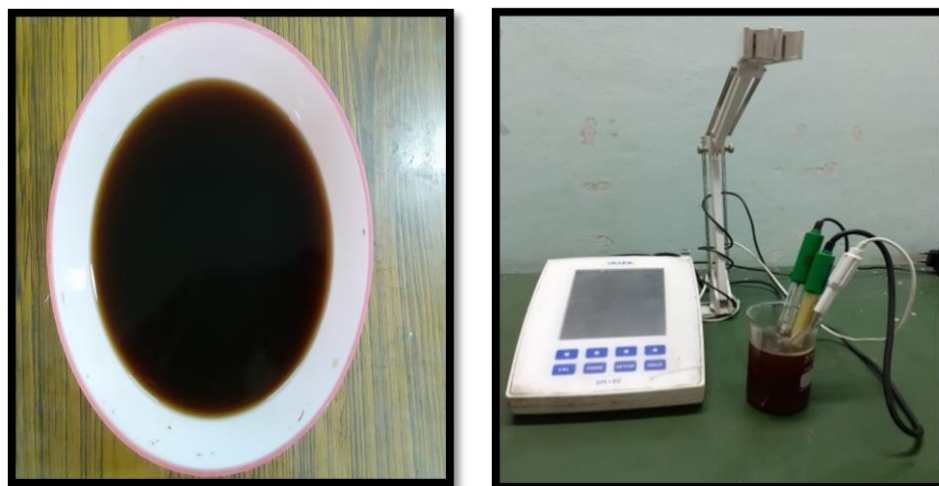


Plate 3.10: Measuring pH and electrical conductivity of jaggery powder

3.3.2.5 Bulk density

Bulk density was determined by following the method described by using Pravallika *et al.* (2018). Bulk density was the mass per unit bulk volume of material where the volume also includes the volume of voids. It was worked out by using the tapping method. The jaggery powder was filled inside a measuring cylinder having a capacity of 100 ml and was tapped. The jaggery powder was allowed to settle down thoroughly inside the cylinder. The tapping of the cylinder was stopped when there is no more settling was observed. Jaggery powder was weighed and the mass of the 100 ml sample was also recorded. The bulk density was calculated using the formulae given in Equation (3.2).

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Mass of sample}}{\text{Volume of sample}} \quad (3.2)$$

3.3.2.6 True density

True density was determined by following the method described by Nighita and Sudagar (2017). The jaggery powder samples were first weighed to determine their mass and the volume for each sample by immersing it in water, to get the volume of displaced water. It is important to note that the readings were taken immediately after the sample was immersing into the jar.

3.3.2.7 Porosity

Porosity was calculated by following the method described by Nighita and Sudagar (2017). The ratio of the difference between the true and bulk density, expressed in percentage as expressed in the Equation (3.3).

$$P = \left[1 - \frac{\rho_b}{\rho_t} \right] \times 100\% \quad (3.3)$$

where, P is the porosity (%), ρ_b is the bulk density (kg/m^3) and ρ_t is the true density (kg/m^3).

3.3.2.8 Total soluble solids (°Brix)

The total soluble solids of jaggery powder was determined by following the procedure reported by Baboo and Anwar (1995) using LCD digital bench refractometer (ATAGO Pocket Refractometer). The 65 gram of jaggery powder sample was taken in a beaker and dipped in 500 ml water and this solution was used for the analysis. Firstly set zero and few drops of the solution were taken over the screen of a refractometer and the start button was clicked on the refractometer screen. The reading appeared on the screen and was noted.



Plate 3.11: Total soluble solids analysis

3.3.2.9 Color evaluation

The color evaluation of jaggery powder was done using the methods reported by Sahu *et al.* (2019) using the Color reader (Konica Minolta Sensing, CR-10). Jaggery powder samples were taken in a clean and dry petri plate with a closed lid. The instrument was kept above the Petri plate and the button was clicked on the right side. The color reader reading appeared on the screen and was noted in L*, a* and b* values.

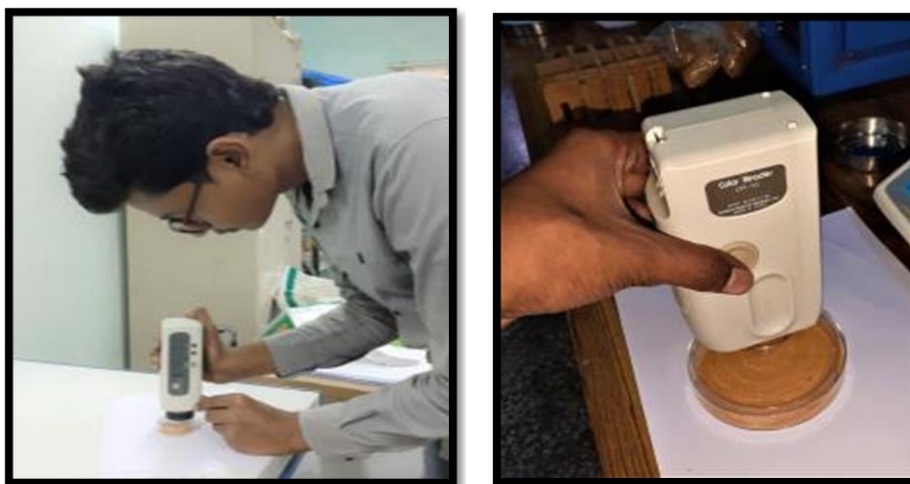


Plate 3.12: Analysis of color values of jaggery powder

3.3.1.10 Solubility

The Solubility of the jaggery cube was determined using the method followed by Baboo and Anwar (1995). Dissolve 10 g of sample in 200 ml of distilled water. Filter the solution through a tared and oven-dried filter paper (Whatman grade) and wash thoroughly. Also, the room temperature was determined using the Rh and temperature meter. Dry the filter paper in a hot air oven at 60-80°C for 8 hrs. Record the weight of dried matter. Express the result as a percent (%) of jaggery cube mas using the Equation (3.4).

$$\text{Solubility} = \frac{W_{iw}}{W_{iw} - W_f} \times 100 \quad (3.4)$$

where, W_{iw} is the initial weight of the sample (g), W_f is the final weight of the sample after drying (g).

3.3.3 Development and fabrication of manually operated machine for making jaggery cubes

3.3.3.1 Working principle

The manually operated jaggery cubes making machine was developed for making the jaggery cubes using jaggery powder by feeding the powder into the cube moulding frame's compartment, then manually compressed using up and down movement of compression plate having dies and attached with the threaded rod and rotating handle. A threaded rod with a compression plate was provided so that the operator should be able to transfer hand force on the rotating handle as a force to push down through the rotating handle with a rod. The cube moulding compartment should hold a sufficient quantity of jaggery powder as per the requirement. The jaggery powder will be densified in the form of cuboid and cubes. The jaggery cubes were prepared by compacting the jaggery powder and cubes were removed from the frame by sliding the base plate. The jaggery cubes were dropped into the collection plate and collected manually, then the base plate, collection plate and compression plate were moved back to its initial position for making next batch of jaggery cubes. Then this process was repeated continuously.

3.3.3.2 Modelling and design consideration of the manually operated jaggery cube making machine

The machine was conceived as a low-cost, easy to fabricate, easy to operate, easy to adjust and easy to dismantle unit for adjustment or replacement of threaded rod with handle or various parts of compression plate as well as the sliding base plate and collection plate. The aim was to get uniform dimensions and good quality of the jaggery cubes. Therefore, compression pressure was kept approximately the same at every time of manual jaggery powder compaction.

The model of the machine was prepared (Fig.3.1 and Fig.3.2) and planned to have the jaggery cube moulding frame at the middle for filling the jaggery powder sample inside hollow cuboidal compartments of the moulding frame. The compression plate having cuboidal dies placed at the top of the cube moulding

frame for the compaction of jaggery powder using a rotating handle attached with compression plate. The machine was developed with the feeding, compressing and collection section. The targeted capacity of the jaggery cube making machine was 800-900 cubes hrs^{-1} as per the preliminary experimental results.

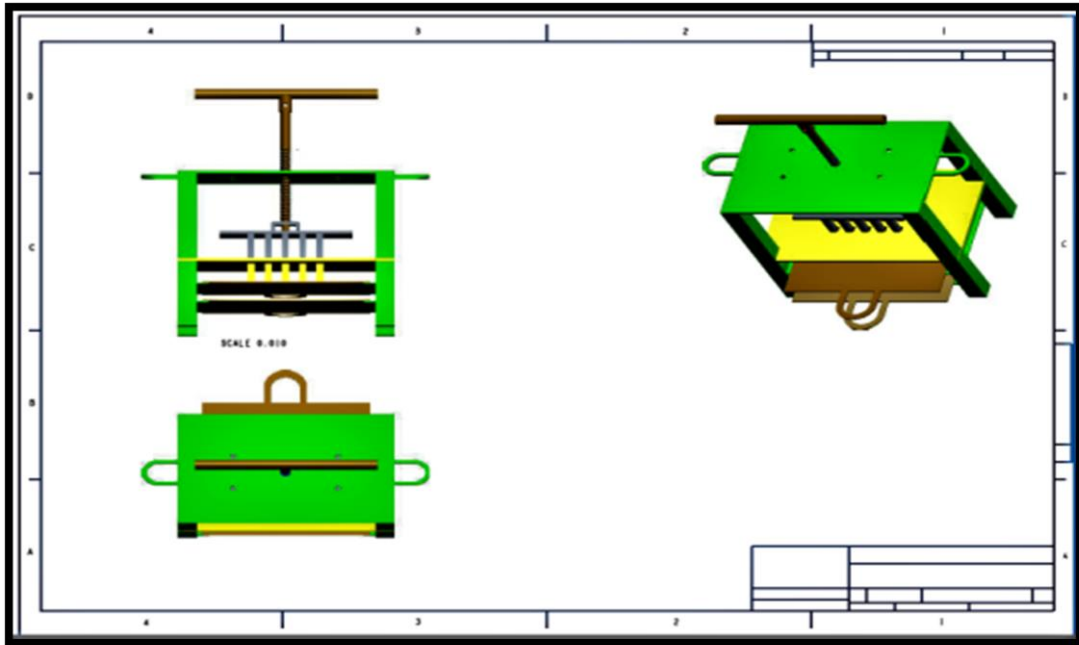


Fig 3.1: Different views in 3D model of the jaggery cubes making machine

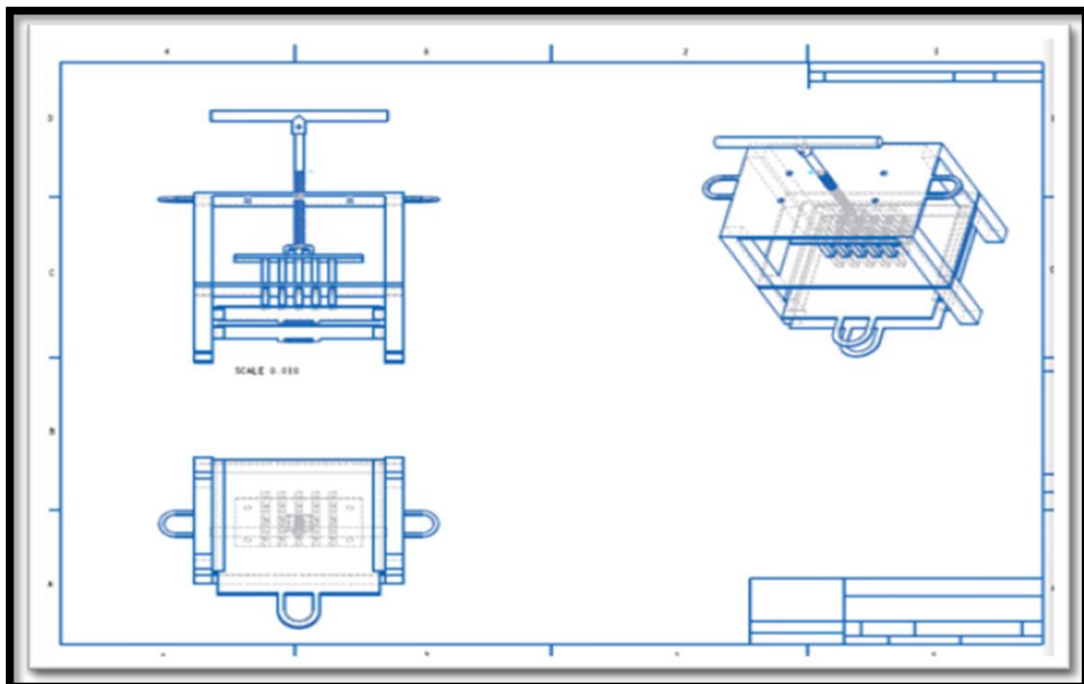


Fig. 3.2: Orthographic views of the jaggery cubes making machine

3.4 Development of Manually Operated Machine for Making Jaggery Cubes

3.4.1 Material estimation

The fabrication of a manually operated jaggery cube machine was carried out using the following

Table 3.2- Specification of material used

Materials	No	Specification (mm)	Parts made/ uses
G.I. sheet	3	Dimension- 450×300×8 Gauge- 8	Upper flat plate
M.S. sheet	2	Dimension-i) 450×300×4, ii) 445×300×4, iii) 445×300×4 Gauge- 8	i) Jaggery cube moulding frame, ii) Sliding base plate, iii) Collecting plate
M.S. Angle	10	Dimension- 450×300×420	Frame stand
M.S. flat compression plate	1	Dimension- 275 ×130 ×8	Compression piston plate
M.S. hollow square rod	20	Outer length- 18 Inner length- 15 Thickness- 3	Jaggery cube moulding frame
M.S. solid square rod	20	Length- 70 Breadth- 14.5 Height- 14.5	Compression cuboidal dies
M.S. solid round rod	4	i) Diameter- 25, Length- 360 ii) Diameter- 12, Length- 260	i) Threaded rod ii) Tension rod

3.4.2 Fabrication of machine

The dimension of the machine components were decided based on the preliminary designing experiments results. The mild steel iron frame with 4 legs was made for supporting all components. A jaggery cube moulding frame was made for making jaggery cubes of equal size and uniform shape by welding a hollow cuboidal rod and mild steel sheet. The dimension of the stand frame was 450 mm×300 mm×420 mm. The jaggery cube moulding frame of dimension 450 mm×300 mm×4 mm with hollow square compartments for making jaggery cubes having the dimension of 15 mm×15 mm× 45 mm. The compression plate was provided with the 20 small cuboidal dies having the dimension of 14.5 mm×14.5 mm×70 mm welded on the M.S. plate having the dimension of 275 mm×130 mm×8 mm, for compressing jaggery powder inside the compartment. The sliding base plate and collecting plate having the same dimension of 445 mm×300 mm×4 mm were fitted in the bottom of the jaggery cube frame for providing base or support during the jaggery powder compaction and collection of jaggery cubes. The tension rod of 260 mm and diameter of 12 mm was fitted by connecting the upper plate, compression piston plate and jaggery cube frame for better vertical up-down movement of the compression plate and threaded rod. The Rotating handle was attached with the compression plate and threaded rod along with bush, plate clamp, viser, cotter lock pin, nut and bolt. The side handle was provided in the machine for better handling and also hole was drilled in the frame's bottom to fix the machine during operation. Some glimpses of the fabrication are shown in Plates 3.14 - 3.19.



Plate 3.13 Marking the rods for cutting



Plate 3.14 Cutting of the plate and rods



Plate 3.15: Drilling of the plate



Plate 3.16: Punching of the flat plate



Plate 3.17: Welding process during fabrication



Plate 3.18: Grinding of the plates and rods

3.5 Performance Evaluation of Manually Operated Jaggery Cube Making Machine Using Jaggery Powder

The Manually operated machine for making jaggery cubes was developed specifically for making the jaggery cubes using the jaggery powder. The electronic balance having a weighing capacity of 10 kg was used to weigh prepared jaggery powder. The jaggery powder with particle sized less than 0.300 mm having a moisture level of 7.00% was selected for the experiment, based on the preliminary experimental results. The jaggery powder was filled into the compartments of the cube moulding frame and jaggery cubes were made by manual compaction. The same manual force was applied during the vertical up-down movement of the compression plate and threaded rod for making identical jaggery cubes. The experimental plan was followed for making jaggery cubes and drying. The 20 g of jaggery powder was used for the experiment. The jaggery cubes were produced by the three operators for the experiment.

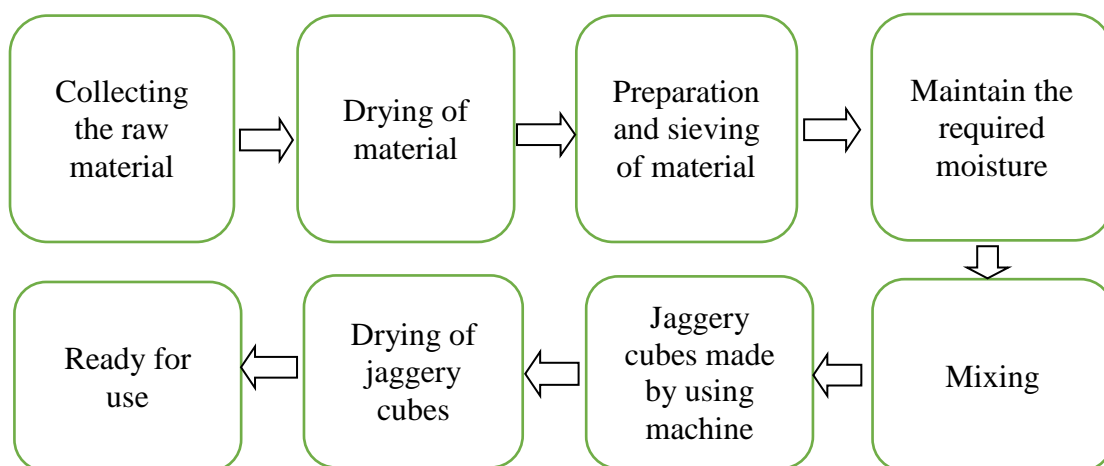


Fig. 3.3: Process flow diagram for making jaggery cube using jaggery cube making machine

3.5.1 Determination of machine capacity

The Capacity of the machine was determined using the method followed by Fadeyibi and Bhattacharya (1992). The machine capacity was determine as the ratio of mass of jaggery cubes, produced by machine, to the average time used in the production of the cubes. Equation (3.5) was used to compute the capacity of the machine.

$$Ct = \frac{mb}{tb} \quad (3.5)$$

where, Ct is the capacity (kg/sec), mb is the mass of cubes produced at time t (kg) and tb is the cubes production time (sec).

3.5.2 Production time

The production time is the total time taken for a complete process cycle (Loading jaggery powder into moulds, compression of jaggery powder and ejection of jaggery cubes) in seconds (sec) for each of the three batches.

3.5.3 Machine efficiency

Machine efficiency is the ratio the mass of sample feed into the machine to the mass of the cubes produced by the material (Fadeyibi and Salman, 2018). This also indicates amount of the useful work perform by the machine. Theoretically, for an ideal material machine system, the machine efficiency is 100%. However practically, this efficiency is often be less than 100% because there may be some materials and energy losses in the cubing and briquitting process (Fadeyibi *et al.*, 2016). In this investigation, the machine efficiency was calculated in Equation (3.6).

$$\Phi = \frac{W_f}{W_b} \times 100 \quad (3.6)$$

where, Φ is the machine efficiency (%), W_b is the mass of sample feed into the machine (kg) and W_f is the mass of cubes produced (kg)

3.5.4 Compressed Volume, Compressed Density, Compression ratio

The compressed volume, compressed density and compression ratio of the jaggery cubes was calculated immediately after ejection of jaggery cubes using the weight and dimensions by following the procedure reported by Taram *et al.* (2017) using the Equation (3.7, 3.8. 3.9)

$$\text{Compressed Volume} = L \times B \times T \quad (3.7)$$

where, L B and T were length (cm), breadth (cm) and thickness (cm) of the jaggery

cubes respectively.

$$\text{Compressed Density} = \frac{M}{V} \quad (3.8)$$

where, M and V was mass (g) and volume (cm) of the jaggery cubes respectively.

$$\text{Compression ratio} = \frac{V_i}{V_f} \quad (3.9)$$

where, V_i and V_f was initial and final volume (g/cm^3) of the jaggery cubes respectively.

3.6 Drying of Jaggery Cubes

Prepared jaggery cubes were dried at various temperatures. The jaggery prepared cubes were weighted accurately and loaded on the drying trays and placed inside the hot air oven dryer. Drying of the jaggery cubes was done using the hot air oven at varying temperatures of 70°C and 80°C . The data were used to analyze reduction in moisture content v/s drying time and drying rate v/s drying time of jaggery cubes was studied, till the moisture level of less than 2% was reached.



Plate 3.19: Drying of jaggery cubes using hot air oven

3.6.1 Drying rate

The reduction in mass of the jaggery cube was recorded at an interval of the one hour during drying process. The drying rate was calculated by following

Equation (3.10) (Garg and Chandra, 2017).

$$\text{Drying Rate (R)} \left(\frac{\text{g}}{\text{h}} \right) = \frac{W_i - W_f}{t} \quad (3.10)$$

where, W_i is the initial amount of moisture, W_f is the final amount of moisture (g) and t is the time taken (hrs).

3.7 Physico-chemical Analysis of Jaggery Cubes Prepared Using Jaggery Cube Making Machine

The jaggery cubes cubes dried at the 80°C using the hot air oven was selected for the physico-chemical analysis as it takes less time for drying with good texture of cubes as compared to jaggery cubes dried at 70 °C.

3.7.1 Moisture content analysis

The moisture content of the jaggery cube was determined following the procedure reported by AOAC (1990) using the oven method. Approximately 1 g of jaggery cube was dried at 105°C for 4 hrs. Moisture content was calculated based on the weight difference before and after the drying procedure. The moisture content of the samples was calculated by following the Equation (3.11).

$$\text{M.C.} = \frac{W_i - W_f}{W_f} \times 100 \quad (3.11)$$

where M.C. is the moisture content (% wb), W_i is the initial weight of sample (g) W_f is the final weight of the sample after drying (g).

3.7.2 Dimensions

The jaggery cube was randomly selected and dimensions were calculated using the vernier caliper scale. with least count of 0.1 mm and accuracy of 0.01 mm. The length, breadth and height of the jaggery cubes were also evaluated.

3.7.3 Weight

The jaggery cube was randomly selected and weight of the jaggery cubes

was determined using the weighing balance with least count of 0.1 mg and accuracy of 0.001 g.

3.7.4 pH

The pH of the jaggery cube was determined following the procedure reported by Baboo and Anwar (1995) using the Hanna pH and conductivity meter. The 13 g of jaggery cube sample was taken in beaker and dipped in 100 ml of water and 0.5 Normality solution was prepared. The digital pH meter electrode was dipped inside the beaker and the reading of pH was noted down.

3.7.5 Electrical conductivity

The electrical conductivity of the jaggery cube was determined by following the procedure reported by Baboo and Anwar (1995) using Hanna pH and conductivity meter. The 13 g of jaggery cube sample was taken in beaker and dipped in 100 ml of water and filled almost completely. The conductivity probe was dipped into the sample up to the mark. The conductivity reading that appeared on the screen was noted in $\mu\text{s}/\text{cm}$.

3.7.6 Total soluble solids (°Brix)

The total soluble solids of jaggery cube were determined following the procedure reported by Baboo and Anwar (1995) using LCD digital bench refractometer (ATAGO Pocket Refractometer). The 65 g of jaggery cube sample was taken in a beaker and dipped inside 500 ml water and this solution was used for the analysis. Firstly setting the zero and few drops of the solution were taken over the screen of a refractometer and then the start button was clicked on screen of refractometer. The reading appeared on the screen was noted.

3.7.7 Color evaluation

The Color evaluation of the jaggery cube was determined following the procedure reported by Sahu *et al.* (2019) using Konica Minolta Sensing, CR-10. Jaggery cube samples were taken in a clean and dried petri plate with a closed lid. The instrument was kept above the petri-plate and the button was clicked on the right side. The color reader reading appeared on the screen and was noted in L^* , a^*

and b^* values. The L indicates the intensity of colour i.e. lightness which varies from $L^*=100$ for perfect white to $L^*=0$ for black. 'a' and 'b' are chromacity dimensions which give understandable designations of colour i.e. the value of a^* measured redness when positive, grey when zero and greenness when negative and the value of b^* measured yellowness when positive, grey when zero and blueness when negative.



Plate 3.20: Determination of color values of jaggery cubes

3.7.8 Density

The density of the jaggery cube was determined using the methods followed by Sahu *et al.* (2019). The toluene sample of 25 ml was taken in a measuring cylinder and 5 gram of jaggery cube was taken. Jaggery cube was dipped inside the measuring cylinder that increases the volume of a toluene solution. The difference in initial volume and final volume of toluene solution were noted down and density was calculated by following the Equation (3.12).

$$\text{Density} \left(\frac{\text{g}}{\text{cm}^3} \right) = \frac{\text{Mass of product}}{\text{Volume of product}} \quad (3.12)$$

3.7.9 True volume

The True volume of jaggery cubes was determined using the methods reported by Nighita and Sudagar (2017). The volume of jaggery cube was measured using water displacement. First, dip the cube by using a sink rod in a few seconds. The difference between the final volume of water displaced and the initial volume gives the volume of the jaggery.



Plate 3.21: True volume analysis of jaggery cubes

3.7.10 Textural analysis

The hardness and resilience of the jaggery cubes was determined using the methods followed by Sahu *et al.* (2019). In Tvt-300 XP software all the data like product name, comment, date, test mode type, force unit, probe, rig, approx. height, headroom above object, compression rate, pre-test speed, post-test speed, test speed, trigger force, data rate, headroom above trigger, batch name, operator name feed-in software and got the graph & table. The rig of P-BP 70A was used. The graph and table shows the values of hardness and resilience.



Plate 3.22: Textural analysis of jaggery cubes

3.7.11 Shattered index

Shattered index was determined by following the method described by Suparin *et al.* (2008), which indicates the durability. This jaggery cube was dropped repeatedly from a specific height of 1.5 m onto a solid metal. The fraction of the jaggery cube retained was used as index of cube breakability. The percentage of

weight loss of jaggery cube was expressed in percentage of the initial mass of the material remaining on the solid base, while by subtracting the percentage weight loss from 100, the shatter resistance was obtained using the Equation (3.13) and Equation (3.14) (Sengar, *et al.*, 2012).

$$\text{Percentage weight loss (\%)} = \frac{W_i - W_a}{W_i} \quad (3.13)$$

where, W_i = Initial weight of cubes before shattering, W_a = Weight of cubes after shattering

$$\text{Shatter resistance (\%)} = 100 - \text{Percentage (\%)} \text{ weight loss} \quad (3.14)$$

3.7.12 Solubility

The Solubility of the jaggery cube was determined using the method followed by Baboo and Anwar (1995). Dissolve 10 g of sample in 200 ml of distilled water. Filter the solution through a tared and oven-dried filter paper (Whatman grade) and wash thoroughly. Also, the room temperature was determined using the Rh and temperature meter. Dry the filter paper in a hot air oven at 60-80°C for 8 hrs. Record the weight of dried matter (Plate 3.23). Express the result as a percent of jaggery cube mass using the Equation (3.15).

$$\text{Solubility} = \frac{W_{jp}}{W_{jp} - W_r} \times 100 \quad (3.15)$$

where, W_{jp} is the initial weight of the sample (g), W_r is the final weight of the sample after drying (g).



Plate 3.23: Solubility analysis of the jaggery cubes and jaggery powder

CHAPTER-IV

RESULTS AND DISCUSSIONS

A review of existing literature and survey indicated that any manual machine for making jaggery cubes using jaggery powder was not been developed and evaluated. Based on the results obtained in various studies carried out in previous sections, a manually operated machine for making jaggery cubes using jaggery powder was developed and evaluated. The manually operated machine for making jaggery cubes was conceived as a low-cost, easy to fabricate and easy to operate the machine. The development of the machine, preliminary designing experimental results, physico-chemical analysis of jaggery powder for designing machine, fabrication of the machine, principles, assembly, performance evaluation of machine, drying and physico-chemical analysis of jaggery cubes are discussed in this section.

4.1 Development of Manually Operated Machine for Making Jaggery Cubes Using Jaggery Powder

4.1.1 Preliminary designing experiment result

- (i) The fine-sized (less than 0.300 mm) jaggery powder having a moisture content of $7\pm 0.5\%$ was selected for the jaggery cubes preparation using jaggery powder inside the cube moulding frame.
- (ii) The jaggery powder having a quantity of 6 g was selected for filling the compartments of moulding frame. The height of the jaggery cubes made inside the mould frame was from 15 mm to 19 mm.
- (iii) The jaggery cube moulding frame having the height of 45 mm was selected with total 20 no. of hollow square compartments in the jaggery cube moulding frame each having dimensions of 15 mm×15 mm×45 mm.

4.1.2 Physico-chemical analysis of jaggery powder

4.1.2.1 Moisture content

The moisture content of jaggery powder taken for the performance evaluation was found 7.00%. The moisture content was found suitable for easy handling and preparing good quality jaggery cubes.

4.1.2.2 Size

The size of the jaggery powder was found to be less than 0.300 mm. The small granular size of the jaggery powder may provide better compaction during the preparation of the jaggery cube.

4.1.2.3 pH

The average value of pH in jaggery powder was 6.178. This value of jaggery powder indicates a slightly acidic nature and suitability for making jaggery cubes.

4.1.2.4 Electrical conductivity

The average value of electrical conductivity was found 2.310 $\mu\text{S}/\text{cm}$. The electrical conductivity was found suitable and does not affect the quality of the cube.

4.1.2.5 Bulk density

The average bulk density of jaggery powder was found 812 kg/m^3 . The bulk density was found good as the better bulk density may provide compacted jaggery cubes.

4.1.2.6 True density

The average true density of jaggery powder was found to be 1046 kg/m^3 . The true density was suitable and may also provide required compaction to jaggery cubes.

4.1.2.7 Porosity

The porosity of jaggery powder was found 22.29%. This low porosity value may provide better compaction during the development of cubes so that compacted jaggery cubes were obtained.

4.1.2.8 Total soluble solids ($^{\circ}\text{Brix}$)

The total soluble solid of the jaggery powder was found 11.9. This value indicates the good level of sucrose content in the solution, which may provide good sweetness to jaggery cubes.

4.1.2.9 Color evaluation

The color values L, a, b of jaggery powder was found 33.8, 1.2, 5.2, respectively. These color values indicate that the powder was moderately dark with a slightly red and yellow in color.

4.1.2.10 Solubility

The solubility of the jaggery powder was 98.67%. The small size of jaggery powder may helped to get good solubility of the jaggery powder.

4.1.3 Design principle and considerations

The manually operated jaggery cube making machine was developed for making good-quality jaggery cubes using jaggery powder (Plate 4.1). The moisture content of the jaggery powder was 7.00 % and prepared jaggery cubes were dried up to less than 2% moisture content to obtain good quality jaggery cubes. The height of the machine was decided based on the convenience of the worker. The mild steel angles, rods, galvanized iron sheet and hollow rods were fabricated. The compression pressure and proper compaction of the jaggery powder may provide a uniform dimension to the cubes. Therefore the compression plate with dies was fitted at top of the jaggery cube moulding frame in the machine.

The jaggery cube making machine was developed for about the capacity of 5-6 kg/hr to suit the domestic and small-scale production industries. A base plate and collecting plate were considered to provide support and to collect the jaggery cubes and were fitted at the bottom of the machine.

4.1.4 Fabrication of the manually operated jaggery cube making machine

As the capacity was envisaged as 5-6 kg/hr, a jaggery cube moulding frame of 450 mm×300 mm×4 mm having small jaggery cube moulding compartments of 15mm×15mm×45mm was found suitable to feed the required material for making jaggery cubes.

(i) Stand frame

The mild steel iron frame with 4 legs was made for supporting all components (Plate 4.1). The dimension of the stand frame was 450 mm×300 mm×420 mm.

Holes are provided in the machine frame's bottom to fix the machine at a suitable place during operation.

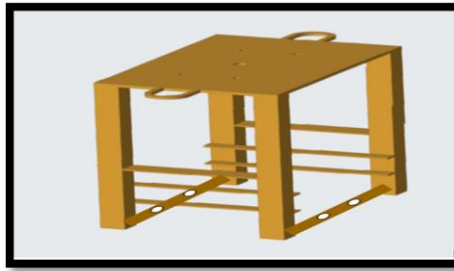


Plate 4.1: Model of the stand frame

(ii) Jaggery cube moulding frame

A jaggery cube moulding frame was provided for making jaggery cubes of equal and uniform shape by welding mild steel hollow cuboidal tube with a mild steel plate (Plate 4.2). The hollow cuboidal tube compartment and mild steel plate for making jaggery cubes had a dimension of 15 mm×15 mm×45 mm and 450 mm×300 mm×4 mm, respectively.

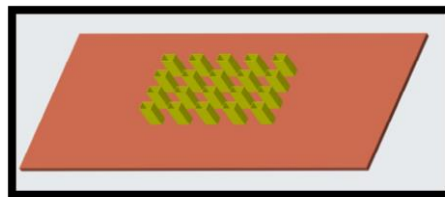


Plate 4.2: Model of the jaggery cube moulding frame

(iii) Sliding base and collecting plate

The sliding base plate and collection plate were fitted in the bottom of the jaggery cube frame for providing base during the jaggery powder compaction and collecting the jaggery cubes having the same dimension as dimension of 445 mm×300 mm×4 mm (Plate 4.3).



Plate 4.3: Model of the collection and base plate

(iv) Compression piston plate

The compression piston plate was provided with the 20 small cuboidal dies

having a dimension of 14.5 mm×14.5 mm×70 mm, welded on the mild steel plate having the dimension of 275 mm×130 mm×8 mm, for the compression of jaggery powder inside the cube moulding frame's compartment (Plate 4.4).

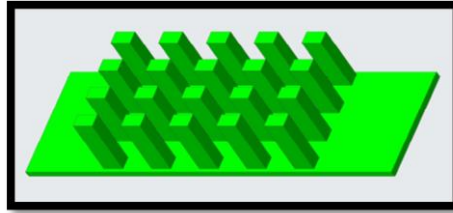


Plate 4.4: Model of the compression plate

(v) Tension rod

The tension rod having a length of 260 mm and a diameter of 12 mm was fitted by connecting the upper plate, compression plate and jaggery cube moulding frame for better movement of the compression plate (Plate 4.5).



Plate 4.5: Model of the tension rods

(vi) Rotating threaded rod with the handle

The rotating threaded rod with the handle having a length 380 mm and a diameter of 25 mm was attached with the compression piston plate and screw rod having threads, bush, plate clamp, viser, cotter lock pin and nut and bolt (Plate 4.6).

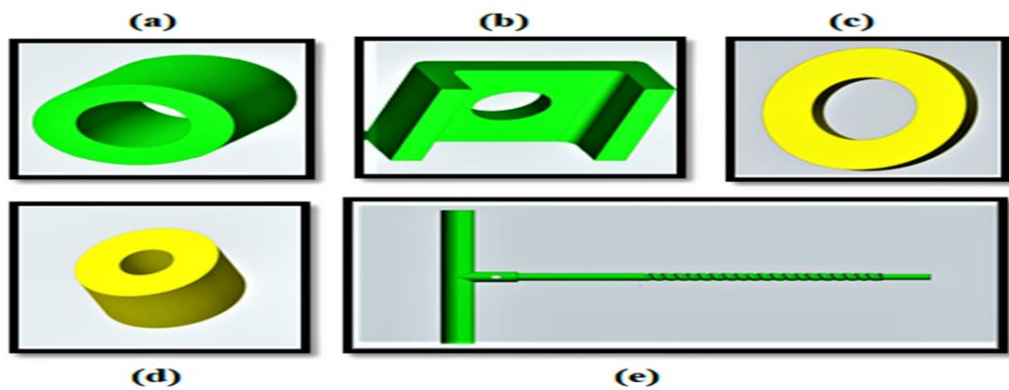


Plate 4.6: Model of a) Check nut b) Clamp c) Viser d) Bush
e) Threaded rod with handle

(vii) Side handle

The side handle was attached on side of the machine's stand frame for easy handling of the machine.

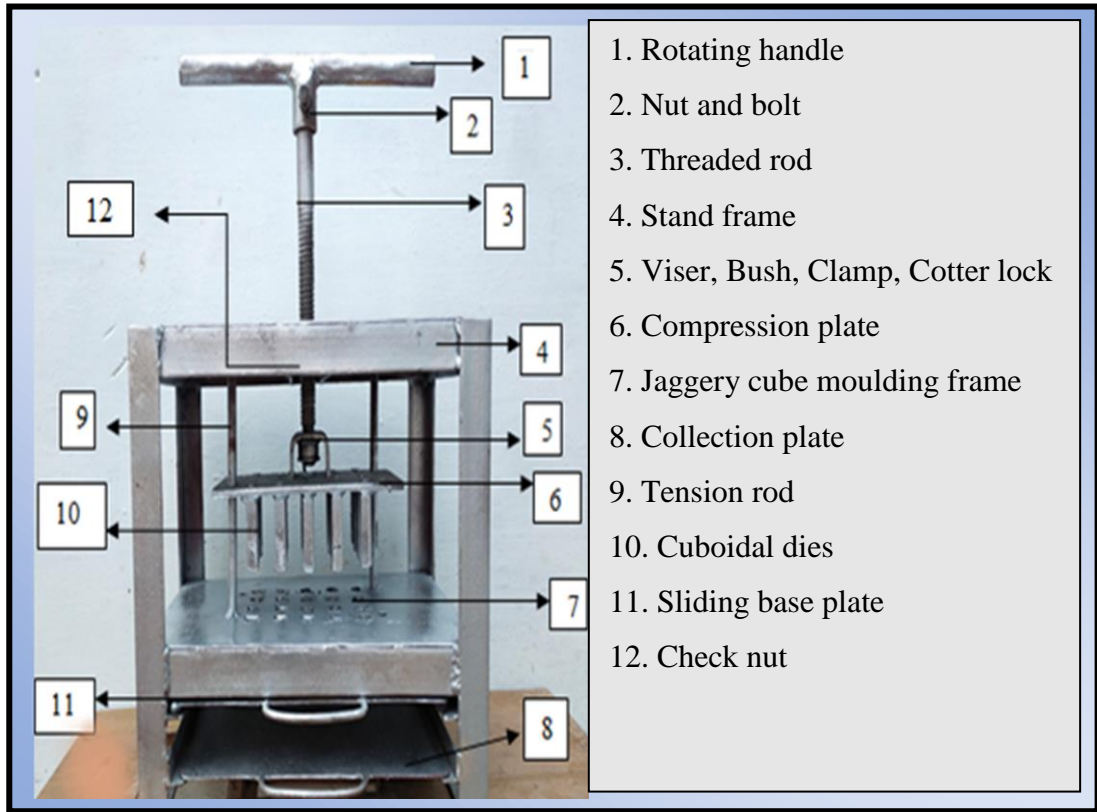


Plate 4.7: Labelled diagram of manually operated jaggery cube making machine

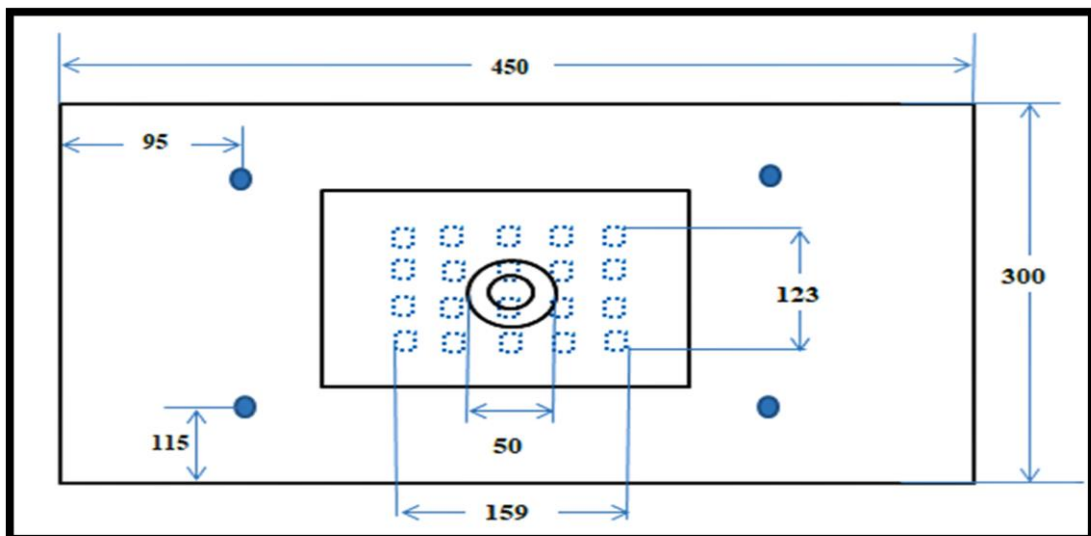


Fig. 4.1: Top view of manually operated jaggery cube making machine (in mm)

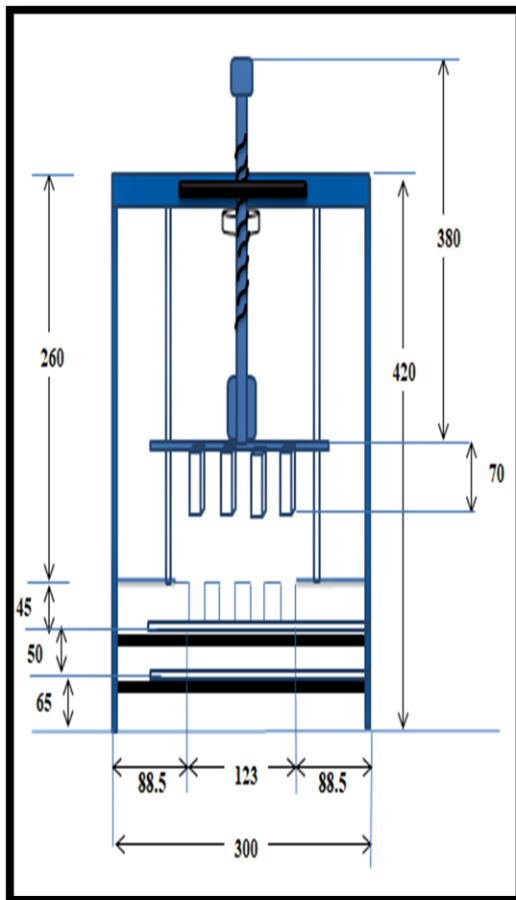


Fig. 4.2: Side view of jaggery making machine (in mm)

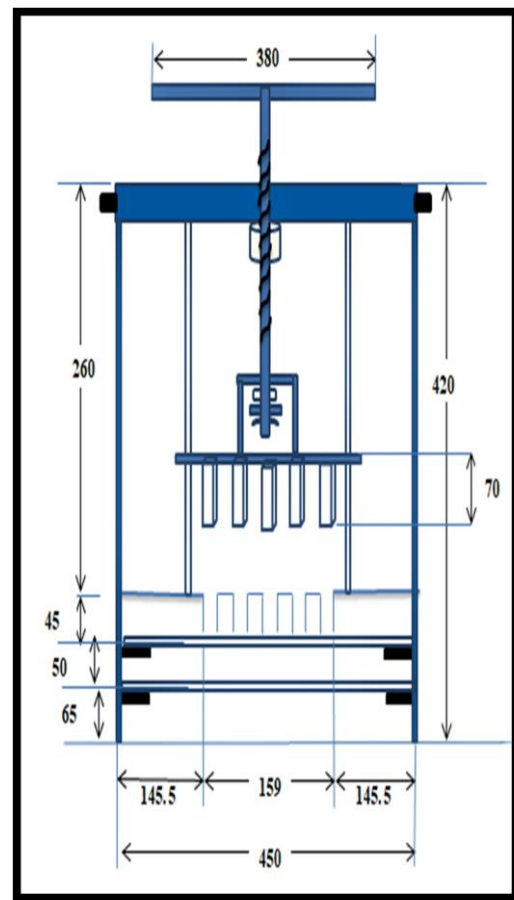


Fig. 4.3: Front view of jaggery cube making machine (in mm)

4.2 Performance Evaluation of Manually Operated Machine for Making Jaggery Cubes Using Jaggery Powder

4.2.1 Production capacity

The production capacity of the machine was about 5.04 kg/hr (tested with the jaggery powder). The machine produces an average of 0.120 kg jaggery cubes or 20 jaggery cubes per batch each cubes weighing 6 g in about 85 sec time frame.

4.2.2 Production time components of the machine

The jaggery powder loading time t_1 , jaggery powder compaction time t_2 , and the mean jaggery cubes ejection time, t_3 , as well as their percentage of the total production time and the corresponding mean mass of jaggery cubes produced, were recorded as shown in Table 4.1.

Table 4.1: Mean production time component of the machine

Mean production time components	Time (sec)	% of total production time
Jaggery powder loading time (t ₁)	25	29.41
Jaggery powder compaction time (t ₂)	40	47.05
Jaggery cubes ejection time (t ₃)	20	23.52
Total	85	100

From above Table 4.1, the mean jaggery powder loading time of 25 sec, mean jaggery powder compaction time of 40 sec and mean jaggery cubes ejection time of 20 sec were recorded, respectively with the total production time of 85 sec per batch.

4.2.3 Machine efficiency

The efficiency of the machine for making jaggery cubes was found to be 98.33 percent. The machine provides good efficiency and less loss of powder which may help to get better productivity and capacity from machine.

4.2.4 Compressed volume

The average value volume of the jaggery cubes was found 3.587 cm³. The highest volume 3.375 cm³ and the lowest volume 3.930 cm³ was observed in samples.

4.2.5 Compressed density

The average value of density of the jaggery cubes was found 1.65 g/ cm³. The highest density 1.50 g/ cm³ and the lowest density 1.75 g/ cm³ was observed. The compressed density may provide better compacted cubes.

4.2.6 Compression ratio

The average compression ratio was found 2.825. The highest compression ratio of 3.00 and lowest compression ratio 2.576 was observed.

Performance Evaluation of Manually Operated Jaggery Cube Making Machine

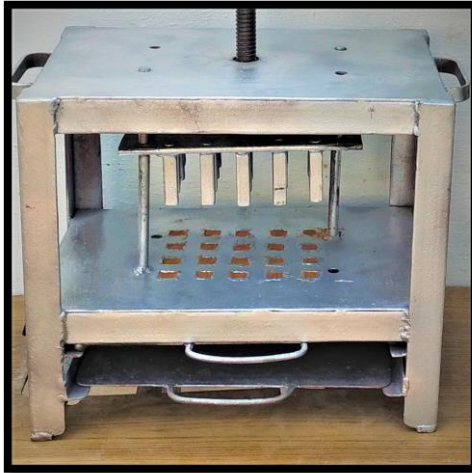


Plate 4.8: Filling jaggery powder inside moulding frame



Plate 4.9: Manual compaction of the jaggery powder



Plate 4.10: Full compression stage of the machine



Plate 4.11: Pulling out the sliding base plate

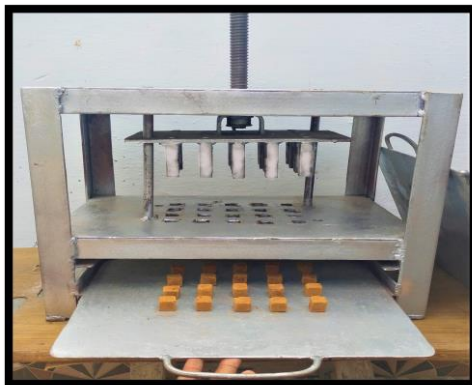


Plate 4.12: Pulling out the collecting plate

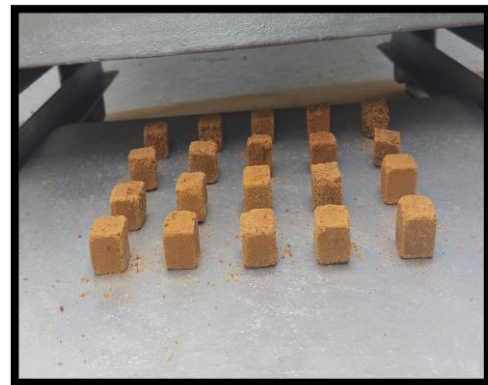


Plate 4.13: Jaggery cubes prepared from machine

4.3 Drying of Jaggery Cubes

The drying behavior of the jaggery cubes was investigated using the hot air drying method at drying temperatures of 70°C and 80°C. The drying curve variation in the moisture content with drying time and air temperature of 70°C and 80°C are shown in Fig. 4.4.

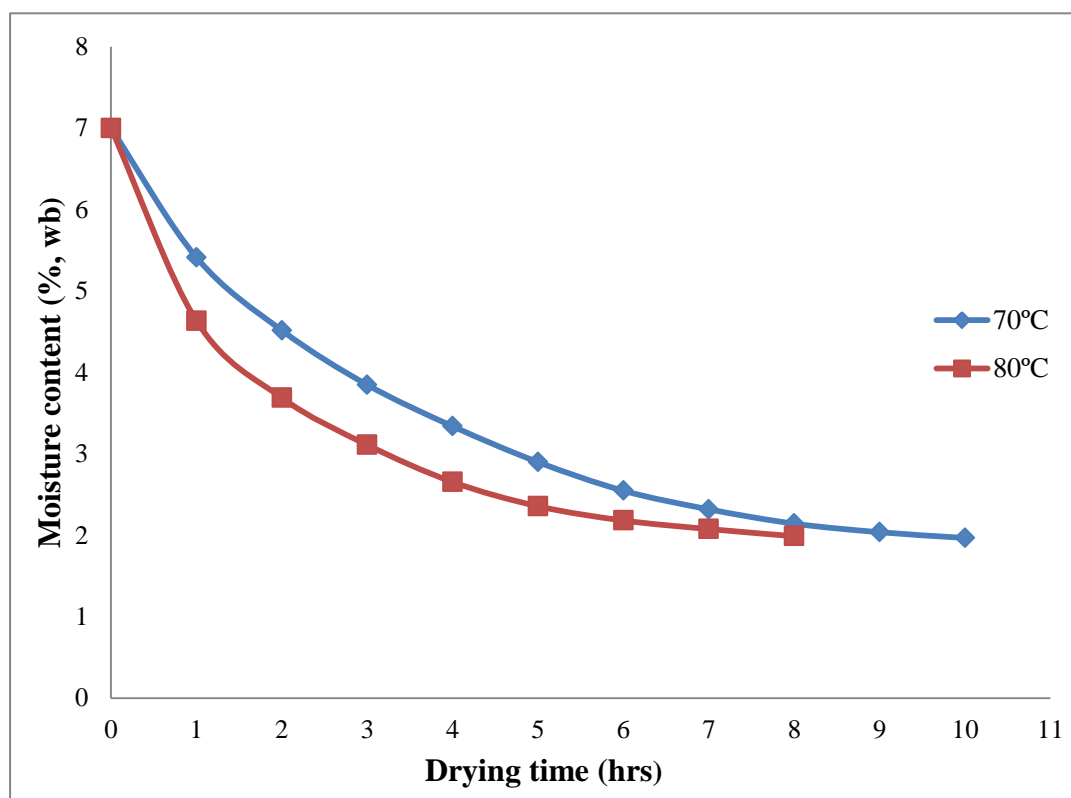


Fig. 4.4: Moisture content vs time graph for drying of jaggery cubes

The initial moisture content of the jaggery cubes was found to be 7.00% (wb). Drying was carried out till the moisture content of the cubes was less than 2%, which was a safe moisture level for the storage. The final moisture content of jaggery cubes are 7.00% to 1.92% and 1.99% (wb) dried using drying temperature of 70°C and 80°C respectively. The data of drying was given in Appendices A and B.

The decrease in moisture content was faster in the initial phase of drying and the end, the decrease in moisture was slow at both drying temperatures under consideration (Fig 4.4). However, at lower temperature i.e. 70°C, the moisture reduction was very less as the drying was approaching towards equilibrium. The

drying time of the jaggery cubes were found at 10 hrs and 8 hrs for temperatures 70°C and 80°C, respectively.

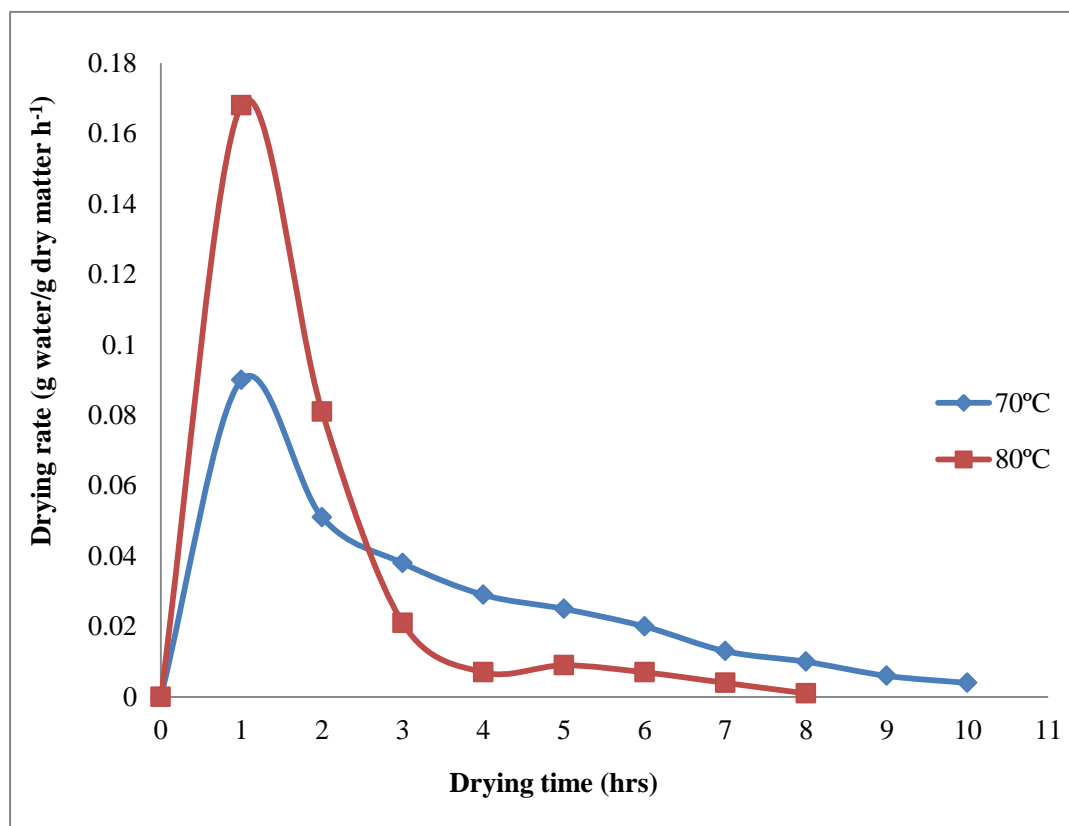


Fig. 4.5: Variation in drying rate with drying time for different drying temperature

The drying curves exhibited steeper slopes as the drying air temperature increased, showing that the drying rate increased with increased drying air temperature, which is a very well-established fact for drying biological material. This is due to the increased energy of water molecules as the temperature increases, according to kinetic theory. As a result, removing molecules was faster and easier from the medium. It has been reported by Prabhanjan *et al.* (1995) that higher temperatures result in higher water vapour pressure and partial pressure of water vapour in air at a given temperature, which is one of the driving forces for moisture diffusion outward (drying).

It has been observed from Fig 4.5 that as the drying proceeds, the sample's moisture content and drying rate both declined. It can also be shown in Fig. 4.5 that the rate of drying was faster when the temperature was higher. This is expected because high drying temperatures evaporate moisture from the sample quickly, resulting in a high drying rate.

4.4 Physico-chemical Analysis of Jaggery Cubes Prepared from Jaggery Cube Making Machine

4.4.1 Moisture content

The moisture content of jaggery powder selected for making jaggery cube was 7.00%. The prepared jaggery cubes were dried ranged 1.92-1.99% for safe storage. A minimum level of moisture content of less than 7 % was selected to reduce the time for drying jaggery cubes.

4.4.2 Dimensions

The average dimension of the jaggery cube prepared from 6 g powder having the length, breadth and height of 15 ± 0.1 mm, 15 ± 0.1 mm and 15 ± 3 mm, respectively. This was suitable for use for the objective. The jaggery cubes dimension should be selected as per requirement.

3.4.3 Weight

The average weight of the jaggery cubes was found 5.699 g. The highest weight of 5.712 g and the lowest weight of 5.690 g were observed in samples.

4.4.4 pH

The pH of the jaggery cube was found 5.714. The highest pH of 5.730 and lowest pH of 5.703 was observed in samples. The pH of the jaggery cubes was suitable for use as a sweetener in beverages and confectionery.

4.4.5 Electrical conductivity

The average electrical conductivity of the jaggery cube was observed 2.686 $\mu\text{S}/\text{cm}$. The highest electrical conductivity 2.900 $\mu\text{S}/\text{cm}$ and the lowest electrical conductivity 2.510 $\mu\text{S}/\text{cm}$. was observed in samples. The electrical conductivity variates much because of the variety of sugarcane and manual preparation methods of jaggery powder.

4.4.6 Total soluble solids (°Brix)

The average total soluble solids of jaggery cubes was found 11.8. This jaggery

cube was found better to use as a sweetener and in beverages.

4.4.7 Color evaluation

The color values L, a, b of jaggery cubes observed were 25.3, 0.5, 7.6 respectively. Due to drying, the cube's 'L' value decrease as it becomes slightly dark. The 'a' value slightly decreases and the 'b' value slightly increases. The color of the jaggery cubes did not vary much and was found suitable as per objectives.

4.4.8 Density

The mean value of jaggery cubes density was found 1.60 g/cm^3 . The highest density of 1.65 g/cm^3 and lowest density of 1.50 g/cm^3 was observed in samples. The values of density show good densified compacted jaggery cubes and may ease storage and drying.

4.4.9 True volume

The average value true volume of the jaggery cube weighing 5.710 g was found 0.00000034 m^3 .

4.4.10 Textural analysis

The hardness of the jaggery cube ranges from 400.66 N - 417.02 N. The highest hardness was observed was found 417.02 N and the lowest was found 400.66 N. The resilience of the jaggery cubes ranges from 0.80 to 0.90. The highest resilience was 0.90 and the lowest 0.80 was observed. The jaggery cubes were suitable for the easy transport and handling

4.4.11 Shattered index

The average percentage (%) weight loss and shatter resistance of the jaggery cubes were found 4.020% and 95.98% respectively. This jaggery cubes shattered less and thus may be good for transportation and packaging.

4.4.12 Solubility

The solubility of the jaggery cubes was 98.50%. The jaggery cubes were

easily dissolvable in the solution and shows good solubility for use as the sweetener.

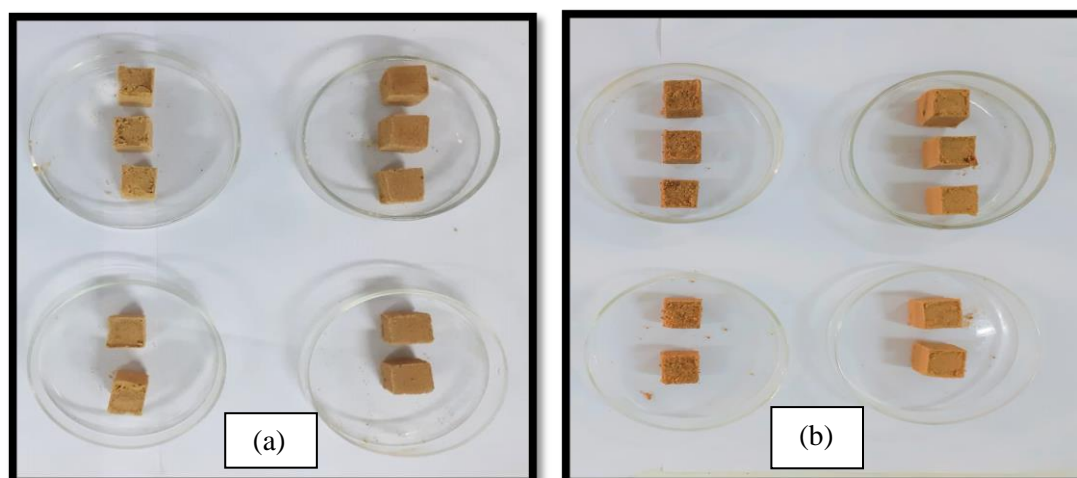


Plate 4.14: (a) Dried jaggery cubes at 70°C using hot air oven.
(b) Dried jaggery cubes at 80°C using hot air oven.

Table 4.2: Physico-chemical properties of prepared jaggery powder and cubes

Physico-chemical parameters		Jaggery powder	Jaggery cubes
Moisture content (% db)		7.00	1.92-1.98
True density (kg/m ³)		1046	-
Bulk density (kg/m ³)		812	-
Density (g/cm ³)		-	1.60
Porosity (%)		22.29	-
pH		6.178	5.703
Electrical conductivity (μS/cm)		2.310	2.686
Total soluble solids (°Brix)		11.9	11.8
True volume (m ³)		-	0.00000034
Solubility (%)		98.67	98.50
Color values	L value	33.8	25.3
	a value	1.2	0.5
	b value	5.2	7.6
Shattered resistance (%)		-	95.98
Hardness (N)		-	400.66-417.02
Resilience		-	0.80 - 0.90

CHAPTER-V

SUMMARY AND CONCLUSION

Sugarcane is a major cash crop of India, which is used for making sugar, jaggery and khandsari. Sugar and khandsari are merely sweeteners but jaggery is a food material as well due to the presence of many important constituents of the human diet. The sugar in the form of cubes is available in the market and has a high-demand for star hotels, flights, family parties and meetings. Under this situation the jaggery powder may also be used for increasing farmer's profit and income by using jaggery powder for preparing jaggery cubes for the domestic and commercial market.

In the present study for easing out this idea, the manually operated machine for making jaggery cubes using jaggery powder was developed and fabricated. The machine has been evaluated for its performance at different operating parameters like time of operation, capacity, etc. Jaggery powder prepared using sugarcane variety of CoLk 94184 (ratoon crop) was selected for the experimentation. It was found that the machine was operated best using the fine sized jaggery powder (less than 0.300 mm) having a moisture content of 7.00%. Jaggery powder and jaggery cubes quality was also assessed. Based on the results, the following conclusions have been drawn:

1. The mean values of moisture content of jaggery powder were found to be 7.00%
2. The average particle size of jaggery powder used for the jaggery cube preparation was less than 0.300 mm.
3. From the experiment carried out, total soluble solids ($^{\circ}$ Brix), pH, electrical conductivity, bulk density, true density and porosity of powder were found 11.9, 6.178, 2.310 $\mu\text{s}/\text{cm}$, 812 kg/m^3 , 1046 kg/m^3 and 22.29% respectively.
4. The color values L, a, b of jaggery powder found were 33.8, 1.2, 5.2.
5. The solubility of the jaggery powder was found 98.67%.
6. The manually operated machine for making jaggery cubes making the jaggery cubes of 6 g with the capacity of 5.04 kg per hrs or 840 jaggery cubes per hrs

was developed. It was operated manually using the jaggery powder of 7.00% moisture content and then dried after preparation.

7. The time of operation was for producing 20 jaggery cubes was 85 sec per batch with the feeding of 0.120 kg per batch of jaggery powder
8. The mean jaggery powder loading time of 25 sec, mean jaggery powder compaction time of 40 sec and mean jaggery cubes ejection time of 20 sec were recorded respectively.
9. The efficiency of the machine for making jaggery cubes observed was 98.33 %.
10. The average value of the compression ratio, compressed volume, compressed density of the jaggery cubes was 2.825, 3.587 cm³ and 1.65 g/cc.
11. Drying of jaggery cubes in a hot air oven at different temperatures showed that drying takes place in the falling period. An increase in drying temperature reduces the drying time.
12. From the experiment carried out, it was generally found out that the characteristics of jaggery cubes produced were satisfactory. The computed moisture, true volume, density, pH, electrical conductivity, total soluble solids (°Brix), shattered resistance, resilience and hardness for all jaggery cubes were 1.92-1.99%, 0.00000034 m³, 1.60 g/cc, 5.714, 2.686 μS/cm, 11.8, 95.80%, 0.80-0.90 and 400.66-417.02 N respectively.
13. The average dimension of the jaggery cubes prepared from 6 g of jaggery powder having the length, breadth and height were respectively 15±0.1 mm, 15±0.1 mm and 15±3 mm.
14. The solubility of the jaggery cube was found 98.50%.
15. The color values L, a, b of jaggery cubes found were 25.3, 0.5, 7.6.
16. The machine was found suitable for small-scale production and for making the jaggery cubes used as sweetener in the confectionary and beverages.

Suggestion for Future work

1. The mechanical machines should be developed for more capacity using stainless steel.
2. The development of jaggery cubes technology will lead to increase job opportunities and establish entrepreneurs. Appropriate help of government,

nongovernmental organizations and professionals has to be performed. Also, further research on the design and construction of the jaggery cubes technologies needs to be done.

3. Moreover, the design and construction of compression die and appropriate material for jaggery cubes, characterization cubes, scaling up of the jaggery cubes making machine and its economic viability are open areas of study for this work.

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APPENDIX

APPENDIX - A

Data Sheet 1

Weight of jaggery cube	:	5.690 g
Initial moisture content of jaggery cube	:	7.00%
Atm. air temperature	:	38°C
Drying air temperature	:	70°C

Time (hrs)	Jaggery cube weight (g)	Moisture (g)	Moisture content % (wb)	Moisture content % (db)	Drying Rate
0	5.69	0.398	7.00	7.526	0
1	5.6	0.308	5.413	5.722	0.09
2	5.549	0.257	4.516	4.730	0.051
3	5.511	0.219	3.848	4.002	0.038
4	5.482	0.19	3.339	3.454	0.029
5	5.457	0.165	2.899	2.986	0.025
6	5.437	0.145	2.548	2.614	0.02
7	5.424	0.132	2.319	2.374	0.013
8	5.414	0.122	2.144	2.191	0.01
9	5.408	0.116	2.038	2.081	0.006
10	5.404	0.112	1.968	2.007	0.004

APPENDIX - B**Data Sheet 2**

Weight of jaggery cube	:	5.709 g
Initial moisture content of jaggery cube	:	7.00%
Atm. air temperature	:	38°C
Drying air temperature	:	80°C

Time (hrs)	Jaggery cube weight (g)	Moisture (g)	Moisture content % (wb)	Moisture content % (db)	Drying Rate
0	5.709	0.303	7.00	7.526	0
1	5.574	0.135	4.634	3.110	0.168
2	5.52	0.054	3.688	3.830	0.081
3	5.487	0.033	3.110	3.210	0.021
4	5.461	0.026	2.655	2.727	0.007
5	5.444	0.017	2.357	2.414	0.009
6	5.434	0.01	2.182	2.231	0.007
7	5.428	0.006	2.077	2.121	0.004
8	5.423	0.005	1.989	2.030	0.001



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