

**DEVELOPMENT AND EVALUATION OF RICE HUSK
BASED GASIFIER FOR THERMAL APPLICATION**

A thesis submitted to the

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DAPOLI – 415 712, MAHARASHTRA (INDIA)

In the partial fulfillment of the requirements for the degree of

MASTER OF TECHNOLOGY

(AGRICULTURAL ENGINEERING)

in

RENEWABLE ENERGY SOURCES

By

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(Reg.No. ENDPM -2016/106)



**DEPARTMENT OF ELECTRICAL AND OTHER ENERGY SOURCES,
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TABLE OF CONTENTS

Title	Page No.
CANDIDATE'S DECLARATION	i
CERTIFICATES	ii-iv
ACKNOWLEDGEMENT	v-vi
TABLE OF CONTENTS	vii-ix
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF PLATES	xii
LIST OF ABBREVIATIONS AND SYMBOLS	xiii - xv
ABSTRACT	xvi - xvii
I. INTRODUCTION	1 – 3
II. REVIEW OF LITERATURE	4-12
2.1 Properties of rice husk	4 – 6
2.2 Gasification of rice husk	6 – 11
2.3 Mango production, processing and pulp boiling	11 – 12
III. MATERIAL AND METHODS	13 – 27
3.1 Study of traditional methods of mango pulp boiling	13
3.2 Development of rice husk based gasifier for thermal application	13
3.2.1 Energy needed	14
3.2.2 Energy input	14
3.2.3 Reactor diameter	15
3.2.4 Height of reactor	15
3.2.5 Cost of rice husk based gasifier	19
3.3 Techno- economic evaluation of rice husk based gasifier	20

3.3.1	Performance of rice husk based gasifier for thermal application	20
3.3.1.1	Laboratory testing of rice husk based gasifier	20
3.3.1.2	Field testing of rice husk based gasifier	24
3.3.2	Economic evaluation of rice husk based gasifier	25
3.4	Instruments used during study	27
IV.	RESULTS AND DISCUSSIONS	28 – 36
4.1	Study of traditional methods of mango pulp boiling	28
4.2	Performance evaluation of rice husk based gasifier	29
4.2.1	Properties of fuel	29
4.2.2	Laboratory testing of rice husk based gasifier	30
4.2.2.1	Operational characteristics	31
4.2.2.2	Thermal efficiency by water boiling test	32
4.2.2.3	Thermal profile of rice husk based gasifier	32
4.3	Field testing of rice husk based gasifier	35
4.4	Economic evaluation of rice husk based gasifier	36
V.	SUMMARY AND CONCLUSIONS	37 – 38
5.1	Summary	37
5.2	Conclusions	38
VI.	BIBLIOGRAPHY	39 – 43
VII.	APPENDICES	44 – 64
	Appendix I – Study of traditional method of mango pulp boiling	44
	Appendix II – Design parameters of rice husk based gasifier	45-46
	Appendix III– Fabrication cost of rice husk based gasifier	47
	Appendix IV – Characterization of rice husk	48
	Appendix V – Operating parameters of rice husk based gasifier	49-52
	Appendix VI – Operating parameters of rice husk based gasifier (Laboratory test)	53
	Appendix VII-Standard Water Boiling Test for rice husk based gasifier	54-59

Appendix VIII – Thermal profile of rice husk based gasifier	60-61
Appendix IX – Operating parameters of rice husk based gasifier (Field test)	62
Appendix X – Economic evaluation of rice husk based gasifier	63-64

LIST OF TABLES

Table No.	Title	Page No.
3.1	Technical specification of rice husk based gasifier	19
3.2	Instruments used during study	27
4.1	Proximate analysis and calorific value of rice husk	29
4.2	Operational characteristics of rice husk based gasifier (Laboratory Test)	31
4.3	Operational characteristics of rice husk based gasifier (Field Test)	35

LIST OF FIGURES

Fig. No.	Title	Page No.
3.1	Schematic front view of developed rice husk based gasifier	17
3.2	Schematic view of rice husk based gasifier	17
4.1	Thermal profile of rice husk based gasifier at desired locations	33
4.2	Surface temperature profile of rice husk based gasifier	34
4.3	Flame temperature of rice husk based gasifier	35

LIST OF PLATES

Plate No.	Title	Between Pages
3.1	Study of traditional method of mango pulp boiling	13-14
3.2	Ash chamber box	18-19
3.3	Ash holder screen	18-19
3.4	Side view of developed rice husk based gasifier	18-19
3.5	Water temperature measurement during standard water boiling test	24-25
3.6	Standard water boiling test during laboratory testing of rice husk based gasifier	24-25
3.7	Thermal profile test during laboratory testing of rice husk based gasifier	24-25
3.8	Mango pulp boiling during field testing of rice husk based gasifier	24-25
3.9	Digital thermometer	27-28
3.10	Wind Anemometer	27-28
3.11	Muffle furnace	27-28
3.12	Hot Air Oven	27-28
3.13	Bomb calorimeter	27-28
3.14	Electronic Balance	27-28
3.15	Measuring Cylinder	27-28
3.16	Digital Stopwatch	27-28
3.17	Infrared thermometer	27-28
3.18	Digital thermometer	27-28

LIST OF ABBREVIATIONS

Abbreviations	Description
Agri.	Agricultural
ASTM	American Society for Testing of Materials
BCR	Benefit cost ratio
BIS	Bureau of Indian Standards
Cal	Calorie
CH ₄	Methane
Cm	Centimeter
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
CV	Calorific Value
Dr. B. S. K. K. V.	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
E	East
Engg.	Engineering
EOES	Electrical and Other Energy Sources
<i>et al.</i>	Et. Alia (and other)
etc.	Etcetera
FAO	Food and Agriculture Organisation
Fig.	Figure
h	Hours
h/kg	Hour per kilogram
i.e.	That is
J	Joule
J/kg	Joule per kilogram
Kcal/kg	Kilo calorie per kilogram
kg	Kilogram
Kg/h	Kilogram per hour
Kj	Kilo Joule
kJ/h	Kilo Joule per hour
kJ/kg	Kilo Joule per kilogram
kW	Kilo Watt
M	Meter

M.C.	Moisture content
m/sec	Meter per second
m ²	Square meter
m ³	Cubic meter
m ³ /h	Cubic meter per hour
Min	Minute
MT	Metric tone
N	North
no.	Number
Ppm	Parts per million
Rs.	Rupees
S	Second
Sr. no.	Serial Number
U. S.	United States
Vol.	Volume
W	West
W	Watt
w.b.	Wet basis
WBT	Water Boiling Test
W/m ²	Watt per square meter
W/m ² °C	Watt per square meter degree Celsius
Wt.	Weight

LIST OF SYMBOL

Symbols	Description
@	At the rate
.	Full stop
,	Comma
+	Addition
-	Subtraction
×	Multiplication
%	Per cent
&	And
⁰ C	Degree Celsius
°	Degree
\$	US Dollar
λ	Lambda
η	Nita

ABSTRACT

Development and evaluation of rice husk based gasifier for thermal application

by

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In India, most of the energy demand for thermal application in domestic sector is fulfilled by using abundantly available biomass. Rice husks (or rice hulls) are hard protecting coverings of grains of rice. Rice husk, which is a large portion of biomass produced in the rice growing regions, has been laying waste at the rice mills in most part of this country.

Gasification as a process of converting carbonaceous materials into gaseous products using a gasifying medium such as air, oxygen, and steam has been considered as an alternative to combustion of low density biomass materials. Gasification of rice husks has been known as one of the effective technology options for the utilization of this renewable energy resource.

The rice husk based gasifier was developed which consist of all components like hopper, burner with secondary air inlet, reactor chamber for gasification, outer body, ash holder screen, primary air inlet fan box, fan for airflow, ash chamber box, stand for holding utensil, caster wheels and insulation. The capacity of the developed gasifier for meeting the heat required to boil the mango pulp per batch. The physical parameters of the traditional method were considered as capacity, fuel type, its

consumption rate, and time required for mango pulp boiling. To evaluate performance of developed rice husk based gasifier were taken in terms of laboratory test and field test.

The proximate analysis and calorific value of rice husk (*Oriza sativa*) revealed its suitability for gasification. The average thermal efficiency (22.63 per cent) of rice husk based gasifier was found to be higher than traditional method of mango pulp boiling indicates the greater conversion of fuel in to heat, with clean environment. The field testing of rice husk based gasifier revealed that the saving of fuel was 2.1 kg per batch over the traditional method of mango pulp boiling. The economic evaluation of rice husk based gasifier revealed that, total saving of Rs. 8430/- against the traditional method of mango pulp boiling and payback period was found 1.2 years which revealed the economic feasibility for mango pulp boiling and other boiling application.

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2018

CANDIDATE'S DECLARATION

I hereby declare that the experimental work and its interpretation of the thesis entitled "Development and Evaluation of Rice Husk Based Gasifier for Thermal Application" or no part thereof has been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/publication of any University or scientific organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

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This is to certify that the research project report entitled "**Development and Evaluation of Rice Husk Based Gasifier for Thermal Application**" submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in **RENEWABLE ENERGY SOURCES** embodies the result of **bonafied** research work carried out by **Mankar Manish Shivdas (Reg. No. ENDPM-2016/106)** under my guidance and supervision. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.

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I. INTRODUCTION

In India, most of the energy demand for thermal application in domestic sector is fulfilled by using abundantly available biomass. Biomass fuels and residues can be converted to energy via thermo-chemical and biological processes. Rice (*Oriza sativa*) is one of the most important food crops of India. It is the staple food of most of the people of South – East Asia. Asia accounts for about 90% and 91% of world's rice area and production respectively. Among the rice growing countries, India is having the largest area under the rice in the world and in case of production it is next to China. However productivity of India is much lower than that of Egypt, Japan, China and Vietnam (Directorate of rice development, GOI, Patna 2009).

India is the second largest producer and consumer of rice in the world after China. Rice husks (or rice hulls) are hard protecting coverings of grains of rice. Rice husk, which is a large portion of biomass produced in the rice growing regions, has been laying waste at the rice mills in most part of this country. Paddy comprises of 62-68% of milled rice, 4-5% of rice bran, 20-25% of rice husk and 2-8% of germ. India has the largest area under rice i.e. 43.4 million hectares and produced 103.41 million tonnes of rice in year 2016-17 accounting for 22.25% of global production in that year. (Khobragade, 2015)

Maharashtra ranks 13th place in rice production in country. In Maharashtra rice was grown over an area 1.56 million hectares with annual rice production of 2085 million tonnes in year (2016-17). The average productivity of the rice in Maharashtra state is 1832.0 kg/ha (Agricultural outlook, 2016). Rice is staple food of Konkan region of Maharashtra. It is grown in 4.136 lakh hectares with production of 10.42 lakh tonnes and productivity is 2.56 tonnes per hectare.

The primary advantage of rice husk as a source of energy is its availability. Large quantities of rice husk are generated annually as a major by-product in the rice milling industry. The estimated worldwide rice husk production per year is about 100 million tons, 90% of which are generated in the developing countries. The use of rice husk also reduces the potential environmental problems which might be generated from storage or open burning of large volumes of rice husk. Rice husk is a major by product of the rice milling industry, is one of the most commonly available lignocellulosic material that can be converted to different feedstock through a variety

of thermo chemical conversion process. During milling of paddy, about 78% of weight is received as rice, broken rice and bran. Rest 22% of the weight of paddy is received as husk. The rice husk contains about 75% organic volatile matter and the balance 25% of the weight of husk is converted into ash during the firing process is known as rice husk ash. This Rice husk ash in turns contains around 85% - 90% amorphous silica. The moisture content ranged from 8.68 to 10.44% and the bulk density ranged from 86 to 114Kg/m³.s. The average calorific value of rice husk is 12-18 MJ/kg (Anonymous, 2006).

At present rice husk is mostly used in small-scale boilers in process industries but these boilers do not have provision to capture fly ash and un-burnt carbon, which result in an extensive pollution being created. The rice husks consist of amorphous silica which create the problem in direct burning as well as forms the clinkers. The briquetting of rice husk needed the large pressure and binder due to its physical properties. The binding of rice husk alone required large pressure and external energy.

The thermo-chemical conversion of biomass (pyrolysis, gasification, combustion) is one of the promising routes among the renewable energy option of future energy. The biomass gasification has attracted the highest interest as it offers higher efficiencies compared to combustion and pyrolysis. The producer gas produced through gasification is more versatile in its use than the original solid biomass. It is burnt to produce process heat and steam or used in gas turbines to produce electricity (Sheth and Babu, 2009).

Biomass gasifier technology offers high thermal efficiency, good process controllability, economic viability and environmental acceptability while using agro and forestry residues available in rural areas and biomass based industries (Patel *et al.*, 2006). Apart from its commercial viability, the system is pollution free, eco-friendly and provides direct energy for heating and boiling of food. The static bed (or “open core”) gasifier is a simple reactor technology available principally for small-scale or remote applications requiring fuel gas for heat or power. The reactor top can be left open for refueling (Tiangco *et al.*, 1996). Biomass based open core down draft gasifier system perform constantly well in industries for thermal application which means of energy conversion. There is huge scope to conserve fossil fuel and reduction in greenhouse gases as well (Rathore *et al.*, 2008).

Gasification as a process of converting carbonaceous materials into gaseous products using a gasifying medium such as air, oxygen, and steam has been considered as an alternative to combustion of low density biomass materials. Gasification of rice husks has been known as one of the effective technology options for the utilization of this renewable energy resource.

India is the largest producer of mango in the world, contributing to nearly 46% of the total world production. The mango pulp manufacturing is one of the wide spread business in the rural area. The boiling of pulp during processing required large heat which can be meet from wood or electricity. For mango pulp production, fully ripe mangoes are washed, peeled and cut into slices. The slices are then homogenized into pulp which is filtered through a sieve to remove the fibres. The pulp is heated to 76-78°C and 2 g citric acid and 2 g potassium metabisulphite are added per kg of pulp. It is filled in sterilized glass jars and lids are sealed with wax (Anonymous, 2016).

Mango pulp is also prepared by mixing 1/3 of fresh or stored pulp with 2/5 of water. Sugar and citric acid are so added that total soluble solids (T.S.S.) and acidity of the product reaches to 15 per cent and 0.3 per cent, respectively. The mixture is heated to 95°C, filled hot in clean, sterilized bottles and crown corked. The bottles are sterilized in boiling water for 10-15 minutes, cooled to room temperature and stored. The procedure for nectar preparation is similar to that of juice except that the pulp percentage is reduced to 15 %. The rice husk gasification for thermal application will be the solution for providing the clean and efficient heat for the mango pulp processing in rural industries (Anonymous, 2016).

The present investigation is therefore undertaken to developed the rice husk based gasifier for thermal application with following objectives.

1. To develop the rice husk based gasifier for thermal application.
2. To evaluate the performance of developed rice husk based gasifier.

II. REVIEW OF LITERATURE

The work carried out internationally and countryside about the development of rice husk based gasifier is reviewed in order to fulfill the proposed objective. The reviewed literatures were arranged under the following titles.

- Properties of rice husk
- Gasification of rice husk
- Mango production, processing and pulp making

2.1 Properties of rice Husk:

Hwang and Chandra (1997) determined the chemical composition of rice husk which was similar to that of many common organic fibers and it contained cellulose 40-50 percent, lignin 25-30 percent, ash 15-20 percent and moisture 8- 15 percent.

Prasad *et al.* (2000) revealed that paddy consists of about 72 percent of rice, 5-8 percent of bran, and 20-22 percent of husk. The ash of rice husk contains the highest proportion of silica. It was estimated that every tone of paddy produces about 0.20 tones of husk and every tone of husk produces about 0.18 to 0.20 tons of ash, depending on the variety, climatic conditions and geographical location.

Maeda *et al.* (2001) showed that there were two distinct stages in the decomposition of rice husk - carbonization and decarbonation. Carbonization was the decomposition of volatile matter in rice husk at temperature greater than 300°C and released combustible gas and tar. Decarbonation was the combustion of fixed carbon in the rice husk char at higher temperature in the presence of oxygen.

Bronzeoak (2003) reported that rice husk was a potential material, which was amenable for value addition. The usage of rice husk either in its raw form or in ash form was many. Most of the husk from the milling was either burnt or dumped as waste in open fields and a small amount was used as fuel for boilers.

Gidde (2007) reported that rice husk was utilized where it was produced on small scales in brick kilns as a fuel. Despite having so many well established uses of

rice husk, it was waste where large quantity was generated, especially in the southern, northern and eastern states.

Madhiyanon *et al.* (2010) described the devolatilization of rice-husk started at around 180–350 °C, volatile and char combustion took place at around 350–500 °C, and at around 500 °C, no further changes in weight were observed, implying that devolatilization and combustion of biomass with high volatile matter content, such as rice-husk, occurred instantaneously with feeding into the combustor and exposure to high combustor temperatures (>1000 °C).

Srinath and Reddy (2011) studied the proximate analysis of rice husk. The moisture content, volatile matter, ash content and fixed carbon were carried out. It was observed that rice husk had 6.1% moisture content, 58.40% volatile matter, 20.6% ash content and 14.9% fixed carbon. In ultimate analysis of rice husk had 36.4% Carbon, 4.84% Hydrogen, 25.11% Oxygen, 0.44% Nitrogen and 0.17% Sulphur. The calorific value of the rice husk was 3420 kcal/kg.

Kumar *et al.* (2013) conclude that the utilization of rice husk could solve the disposal problem and reduce the cost of waste treatment. Rice Husk and its ash were used directly for manufacturing and synthesizing new materials. It was used as a fuel, fertilizer, substrate and it also used in preparation of activated carbon, pet food fiber, Silica and silicon compounds, bricks etc. Easy availability and low price of rice husk in rice producing countries was an extra benefit towards the use of this material. Therefore abundantly and renewability of rice husk represents a real advantage over source of dwindling fossil fuels for bioethanol production.

Bie *et al.* (2014) conclude that, in muffle furnace, rice husk could burn more completely at low temperature (about 600 °C) than high temperature. At high temperature, K₂O could decompose that causes more residual carbon in rice husk ash and 600 °C was the appropriate temperature for preparation of rice husk ash with large specific surface area due to the existences of nanoscale and amorphous SiO₂. And the present of K had great impact on specific surface area of rice husk ash. It could obvious decrease with the K content increasing.

Mistry (2016) stated that rice husk is mostly used as fuel in boilers for processing paddy and generation of process steam. Heat energy was produced through direct combustion. Small sector process industries use fixed low capacity boilers,

which were manually fired using rice husk as a fuel. Partial and uneven fuel combustion leads to smoke emission and decrease the fuel efficiency. As husks were available virtually for free, the boiler efficiency and the degree of combustion were the issues of receiving the latest attention. Plants with capacity 2-10 MW range can become commercially viable and this biomass resource can be utilized to a much greater extent than at present.

Swami Nathen *et al.* (2017) conclude that there were huge amounts of RHA produced as by-product from the Indian rice processing mills, mainly in India, which were disposed to environment without any return price. Thereafter, disposal cost was increased in order to transport this ash also a large land area becomes useless and the fertility of land was reduced. So the problem can be solved or minimized by properly utilizing the rice husks and ash.

2.2 Gasification of rice husk:

Shah (1986) reported that a pack bed of rice char was further reduced the solid particle content of the gas leaving the wet sieve plate scrubber. This was not obvious if one considers the fact that rice hull char contains many fine particles that could be entrained into the gas stream.

Jain *et al.* (1988) revealed that in updraft rice husk gasifier the producer gas composition for one test run with respect to time after operating period for one batch was about 40 minutes when the gasifier was not connected to boiler. The gas composition was constant from 15 minutes after start to 5 minutes before the end of test run. Towards the end the methane content significantly dropped. When the boiler was operated with the gasifier, the batch operation period dropped to 0.25 minute.

Patil *et al.* (1991) reported a rice husk gasifier system installed at food industry and its performance evaluation. By comparing diesel burner based process. The gasifier burner based system showed a saving of Rs. 2 per kg in fuel cost for potato chips processing.

Reed and Larson (1996) studied the operation of inverted downdraft gasifier stove using wood fuel to observed emission during cooking. The testing of wood gas stove on different fuel consumption rate of biomass was observed. The study revealed that the wood-gas stoves and operated indoors with no exhaust fans liberates minimum

pollutants and good thermal efficiency. The fuel consumption rate of gas stove affected the power rating and charcoal production.

Tiangco *et al.* (1996) suggested that the gasifier was a simple reactor technology developed principally for small-scale or remote applications requiring fuel gas for heat or power. The reactor itself consisted of not more than two concentric cylinders (one may be sufficient), in which a stationary fuel bed converted by a reaction front propagated through the fuel bed. The reactor top can be left open for refueling.

Jorapur and Rajvanshi (1997) reported the use of indigenously available agricultural residues to generate producer gas as an attractive alternative in developing countries like India to meet the thermal energy demands of industries. A commercial scale gasifier of 1080 MJ/h (approximately 300 kW) was developed and field tested (in a metallurgical company) to gasify low-density biomass.

Lin (1998) revealed that partial oxidation of rice husk at reaction temperatures below 1000 K recovers amorphous silica materials. Based on the gasification experimental data obtained from the bench-scale downdraft-type reaction system, the basic engineering design for a pilot plant of the rice husk gasification process were accomplished. This process was consisted of a rice husk feed system, a downdraft type gasifier, an ash discharge system, a tar adsorbent, and an internal combustion engine for power generation.

Bhattacharya *et al.* (2001) reported that development of a natural cross-draft gasifier stove at the Asian Institute of Technology for institutional kitchens. Design and experimental results of this stove using wood and rice husk briquette as fuels were presented. The stove operated with practically no smoke as reported. Another advantage of the stove was continuous operation by refilling fuel into the hopper at 1-2 hour intervals. Highest utilization efficiency of the gasifier stove as determined by water boiling test had been found to be about 27% for wood fuel.

Belonio (2005) reported the design, development and evaluation of rice husk open top gasifier stove. The design parameter reported for gasifier stove were energy needed, diameter of cylinder reactor, height of reactor and fuel consumption rate. Two series of test were conducted for evaluation stove i.e. laboratory tests and actual cooking tests. The laboratory test of stove determined the operating parameters,

included the boiling test to determine the efficiency and power output of the stove. The actual cooking test determined the cooking performance of the stove, operational kitchen management operation and economics of the stove.

Bhoi *et al.* (2006) evaluated the open core gasifier on multi-fuels and estimated the gasifier performance in terms of fuel consumption rate, calorific value of producer gas and gasification efficiency. Gasification efficiency of babul wood (*Prosopis juliflora*), groundnut shell briquettes, groundnut shell, mixture of (*Prosopis juliflora*) and groundnut shell in the ratio of 1:1 and cashew nut shell were 72%, 66%, 70%, 64%, and 70%, respectively. Study revealed that babul wood (*Prosopis juliflora*) and groundnut shell in the ratio 1:1 and cashew nut shell were satisfactorily gasified in open core down draft gasifier.

Jain (2006) reported the design parameters for a rice husk throat less gasifier. It was found that the reactor diameter was the most critical parameter for a throat less gasifier. Five open core throat less batch fed rice husk gasifier reactors having internal diameters of 15.2, 20.3, 24.4, 30.3 & 34.3 cm had been designed, fabricated and tested. It was found that for each reactor the gasifier performance was the best at a specific gasification rate of around 200 kg/hr-m². Under the best operating conditions, the equivalence ratio was found 0.40 and the gasification efficiency was around 65%. These parameters could be used for designing rice husk operated throat less gasifiers in the capacity range of 3 kW to 30 kW.

Patel *et al.* (2006) suggested in field testing of SPRERI's open core gasifier for thermal application that heating systems based on wood, fuel oil, electricity and coal/lignite was common in small industries. Environmental pollution, poor process control and high cost were some of the limitation of these systems. On the other hand, biomass gasifier technology offered high thermal efficiency, good process controllability, economic viability and environmental acceptability while using agro and forestry residues available in rural areas and biomass based industries.

Panwar (2009) evaluated the design and performance evaluation of energy efficient biomass gasifier based cook-stove on multi fuels. The stove exhibited about 35 per cent thermal efficiency. The CO and CO₂ emission was in the range of 3-6 ppm and 17-25 ppm respectively. The stove worked in the range of 1.53 to 1.76 kW

of power rating. The maximum flame temperature was recorded as 763⁰C when Cashew nut (*Anacardium occidentale*) shell was used as feed stock.

Rathore *et al.* (2009) addressed the design, performance and economic evaluation of biomass based open core down draft gasifier for industrial process heat application. The techno-economic of the designed system includes system design and economic evaluation. The system design on feed stock consumption rate and dimensions of reactor while the economic evaluation on net present worth, benefit cost ratio and payback period which gave the feasibility of the system. The study revealed that the gasifier had feed rate as 90 kg/hr and producing about 850MJ/hr of heat. The net present worth, benefit cost ratio and payback period of biomass gasifier for industrial thermal applications were found to be US \$ 87400, 1.65 and 2years and 11 months respectively.

Belonio (2010) reported the continuous flow rice husk gasifier models tested successfully operate on a continuous mode. Continuous operation was accomplished by simply loading rice husks onto the feed hopper while simultaneously discharging char from the char box. Rice husk fuel was easily ignited and produces combustible gases within 5 to 30 minutes. Almost no smoke was emitted from the gasifier during operation. One to two persons were needed to operate the continuous flow rice husk gasifier – i.e., to facilitate loading of fuel and unloading of char.

Li *et al.* (2010) revealed that air steam gasification of rice husk were experimentally investigated in a combined fixed-bed reactor with the supported nano-Ni O/g-Al₂O₃ catalyst under various operating conditions, aiming to produce a hydrogen-rich syngas in biomass air steam gasification. The experiments demonstrated that the newly developed nano-Ni O/g-Al₂O₃ catalyst in biomass air steam gasification was promising, with 99% tar removal reached at 800⁰C and the gas yield increased markedly. Especially, the percentage of H₂ in the product gas was obviously enhanced over 10% volume, due to the presence of catalysts. Therefore, using the prepared nano- Ni O/g-Al₂O₃ catalyst in biomass gasification can significantly improve the quality of the produced gas and meanwhile eliminate efficiently the tar generation.

Zhao *et al.* (2012) revealed that the characteristics of the cyclone gasifier to generate the fuel gas with reasonable heating value and less tar content from the rice

husk has been carried out. The optimal ratio of height to inner diameter of the high temperature chamber is 3-4. Considering the problems caused by the tar in the produced gas and ash agglomeration, the optimal equivalence ratio is 0.29 and the maximum gasification temperature should be lower than 1000 °C. Air staged gasification is an effective way to improve the quality of the produced gas for the cyclone gasification of the rice husk. When the secondary air ratio is 30%, the low heating value, carbon conversion, cold gas efficiency and tar content are 4.72 MJ/Nm³, 57.5%, 37.3% and 1.85 g/Nm³, respectively.

Pradhan (2013) revealed that with the increasing industrialization and rapid population growth non renewable fuels are rapidly getting consumed, which may lead to risk of energy shortage in the future, but a definite solution to it is the use of renewable source. India being a major agricultural country, rice husk gasifiers produce a change in the energy scenario of the country.

Mohod *et al.* (2015) evaluated the open top gasifier based community system on multi fuels. The study revealed that, the proximate analysis and calorific value of babul (*Acacia Nilotica*) indicated its suitability for gasification. The average thermal efficiency (21.86%) of open top gasifier was found to be higher than traditional cooking system indicated the greater conversion of fuel in to heat, with clean environment. The field testing of open top gasifier revealed the saving of about 22% of fuel wood (*Acacia Nilotica*) over the traditional cooking system.

Njogu *et al.* (2015) reported that the present study shows great potential for conversion of rice husks into clean gas fuel and carbonized husks. Carbonized husks were used to make energy briquettes and partly applied to the rice growing pads to improve soil properties. The technology provides energy solutions and aids in the abatement of climate change mitigation and abatement since it provides a permanent carbon sink. The technology provides a value addition chain for rice growers.

Zhai *et al.* (2015) revealed that the characteristics of rice husk char with steam are studied by experiments. The conclusions can be made after analyzing the influences of reaction temperature, reaction time and char preparation temperature on the conversion rate and the composition of produced gas of rice husk char. Temperature was the primary factor that influences the steam gasification reaction of rice husk char. When the temperature rises from 700 °C to 950 °C, the conversion rate

of rice husk char increases significantly from 27.7% to 90.73% after reacting for 12 min. The high temperature contributes for the production of H₂. When the temperature was 950 °C, H₂ accounts for 46.9% of the product gas. When the gasification temperature is 950 °C, the conversion rate of rice husk char reaches 98.65% if the char preparation temperature is 600 °C, whereas the conversion rate reduces to 87.3% if the char preparation temperature is 900 °C.

2.3 Mango production, processing and pulp making:

APITCO (1999 a.) reported that accounting to 10% of the global production of fruits, India ranks first in the world. Food processing sector of India plays a vital role in improving the value addition opportunities and creating surplus food for agro-food products. Presently, a mere 2.2 per cent of fruits and vegetables are processed. The National policy of India aims to increase the percentage of food being processed in the country to 25 per cent by 2025. Food processing adds value, enhances shelf life of the perishable agro-food products and encourages crop diversification. Described that mango pulp was the concentrated mango juice obtained from processing of various varieties of mangoes. The processed mango pulp has enhanced shelf life and has significant export potential. The mango pulp can further be used to produce downstream products like mango jelly. The canned mango pulp has about 2 years of shelf life without using a cold storage. Canned mango pulp is consumed as a fruit juice and in the processing of mango jelly.

APITCO (1999 b.) reported that the technology for the manufacture of various canned and bottled fruits and vegetable products was well established. The harvested mangoes were put in ripening chambers or sheds and are periodically checked for further processing. The mangoes are selected, graded, washed and cleaned. The pre-treatment process consists of peeling, deseeding, trimming, sizing and blanching. The pulp is pasteurized and filled into tins or glass containers, which are subjected to exhausting, vacuumising, retorting and cooling.

Ravani *et al.* (2013) revealed that pulp is heated to 85 °C, filled hot into cans and sealed and processed at 100 °C for 20 min and cooled. Addition of ascorbic acid at 100 mg % in the canning of mango pulp helps in the retention of colour, flavour and carotene.

Kaushik *et al.* (2014) conclude that the present study reported the effects of pressure level and processing time on quality attributes of mango pulp. The overall quality of mango pulp was moderately affected by high pressure processing. In addition, it inactivated the indigenous micro flora in fresh mango pulp significantly, with treatment of 600 MPa for 5 min. Thus, high pressure technology was applied to obtain high quality and safe mango pulp.

Kaushik *et al.* (2016) reported that mango (*Mangifera indica*) Amrapali fruits were harvested at their commercial maturity (90-100 days after fruit onset) from Research Farm. Then mango pulp was vacuum packed in Ethyl vinyl alcohol copolymer films were achieved in the packages. Packaged mango pulp was processed in a batch mode HPP system having 2 L capacity cylindrical vessel with 100 mm inner diameter and 250 mm depth. Samples were processed according to a rotatable central composite design (RCCD) at pressures in the range of 400 to 600 MPa, isobaric temperatures in the range of 40 to 60 °C for pressure-hold duration in the range of 5 to 15 min. Prior to HPP, samples were preconditioned in a water bath so that target temperatures (40 to 60 °C) could be achieved upon compression, considering adiabatic heating of $\approx 3^{\circ}\text{C}$. After processing, the samples were immediately transferred to 2 °C to prevent residual effects of processing.

Anonymous (2017) reported that mango pulp was prepared from selected varieties of fresh Mango Fruit. Fully matured Mangoes were harvested, quickly transported to the fruit processing plant, inspected and washed. Selected high quality fruits go to the controlled ripening chambers; Fully Ripened Mango fruits were then washed, blanched, pulped, deseeded, centrifuged, homogenized, concentrated when required, thermally processed and aseptically filled maintaining sterility. The preparation process includes cutting, de-stoning, refining and packing. In case of aseptic product the pulp was sterilized and packed in aseptic bags. The refined pulp was also packed in cans, hermetically sealed and retorted. Frozen pulp was pasteurized and deep-frozen in plate freezers. Mango Pulp was perfectly suited for conversion to juices, nectars, drinks, jams, fruit cheese and various other kinds of beverages.

III. MATERIALS AND METHODS

This chapter deals with the assumption and methodology adopted for development and evaluation of rice husk based gasifier for thermal application. The designed system was fabricated at CAET workshop and tested at Department of Electrical and Other Energy Sources, College of Agricultural Engineering and Technology, Dapoli. The study area falls at 17° 45' N latitude and 73° 26' E longitude and at an altitude of 256 m above mean sea level. The stepwise methodology to accomplish the research work is summarized under the following sub- headings

- Study of traditional methods of mango pulp boiling.
- Development of rice husk based gasifier for thermal application.
- Techno-economic evaluation of rice husk based gasifier for thermal application.

3.1 Study of traditional methods of mango pulp boiling

The study of traditional methods of mango pulp boiling was carried at Asond near Vakavali, Tal-Dapoli. The study conducted for measuring the various parameter of mango pulp boiling process.

Following parameters were noted during the study of traditional methods of mango pulp boiling.

1. Capacity of mango pulp boiling, (pulp per batch),
2. Time required for mango pulp boiling, (min),
3. Boiling point of mango pulp, (°C), and
4. Fuel type and consumption rate, (kg per batch)

The results obtained from the study were summarized in Appendix-I. The pictorial view of traditional method of mango pulp boiling shown in Plate-3.1.

3.2 Development of rice husk based gasifier for thermal application

The development of rice husk based gasifier for thermal application was carried out based on the traditional method of mango pulp boiling and followed in mango pulp industry. The capacity of a proposed gasifier showed the energy needed for meeting the heat required to boil the mango pulp per batch. The physical parameters of traditional method of mango pulp, capacity, fuel type and it's

consumption rate, time required for heating were considered while developing the rice husk based gasifier.

The fabrication work was carried out in the workshop of Department of Farm Machinery and Power, College of Agricultural Engineering and Technology. The fabrication involves cutting and bending of MS sheets to form cylinders and rings, welding, drilling etc.

The following parameters were considered while developing the rice husk based gasifier for thermal application.

3.2.1 Energy needed, (Kcal /h)

The amount of energy required for heating the quantity of mango pulp was considered as the energy output of gasifier system. It was computed as

$$Q_n = m \times C_p \times \Delta t \quad \dots 3.1$$

Where,

Q_n = Amount of heat required, Kcal/hr

m = Mass of mango pulp, kg

C_p = Specific heat of mango pulp, Kcal/kg

Δt = (boiling temperature – ambient temperature)

$$\text{Actual amount of heat needed } [(Q_n)_{\text{actual}}] = \frac{Q_n}{\text{Thermal efficiency}} \quad \dots 3.2$$

$$(Q_n)_{\text{actual for 20 kg of pulp}} = \frac{M_p \times (Q_n)_{\text{actual}}}{T} \quad \dots 3.3$$

Where,

M_p = Mass of pulp, kg

T = Boiling time, h

3.2.2 Energy input, (kg/ h)

The amount of energy needed in terms of fuel to be fed into the gasifier. It was computed as

$$\text{FCR} = \frac{Q_n}{H_{vf} \times \eta_g} \quad \dots 3.4$$

Where,

FCR = Fuel consumption rate, kg/h

Q_n = Energy needed, Kcal/h

H_{vf} = Heating value of fuel, Kcal/kg

η_g = Gasifier efficiency, %

3.2.3 Reactor diameter, (m)

The size of the reactor in terms of the diameter of the section of the cylinder computed as

$$D = \left(\frac{1.27 FCR}{SGR} \right)^{0.5} \quad \dots 3.5$$

Where,

D = Diameter of reactor, m

FCR = Fuel consumption rate, kg/h

SGR = Specific gasification rate of rice husk, kg/m²-h

3.2.4 Height of reactor, (m)

The total distance from the top and the bottom end of the reactor computed as

$$H = \frac{SGR \times t}{\rho r h} \quad \dots 3.6$$

Where,

H = Height of the reactor, m

SGR = Specific gasification rate of rice husk, kg/m²-h

T = Time required to consumed rice husk, h

$\rho r h$ = Rice husk density, kg/m³

Design parameters of rice husk based gasifier were calculated (Appendix-II).

The rice husk based gasifier system mainly consists of following components

- **Hopper**

Hopper was feeding pipe with open core. The hopper of cylindrical gasifier and the reactor was single. The biomass of desired size was fed in the cylindrical gasifier. It was made up of MS pipe of 0.2 m diameter of pipe.

- **Burner with secondary air inlet**

The secondary air inlet supplies the adequate air for complete combustion of producer gas produced during gasification. There were 23 secondary air inlet holes of 10 mm ϕ at the top of inner shell.

- **Reactor chamber for gasification**

The reactor chamber ensures the gasification of biomass which yields the combustible producer gas. The producer gas moves with draft up to the burner. The reactor was made up of mild steel pipe (8 mm thick). The reactor chamber was 1 m in height and 0.2 m in diameter.

- **Outer body**

The outer body of open top gasifier was made up of MS sheet of 16 Gauge (1.6 mm thick) in cylindrical shape. The diameter of cylinder was of 0.26 m. The height of the cylinder was 0.9 m.

- **Ash holder screen**

The ash holder screen was made up of mild steel, which hold the rice husk onto the holder screen of gasifier and ash was allow to fall in ash chamber box. The length and breadth of ash holder screen was 0.27 m and 0.25 m, respectively.

- **Primary air inlet fan box**

The air inlet fan box was used for primary air requirement for gasification. It also provides the necessary draft required for gasification of biomass. The length, breadth and height of box were 0.137, 0.130 and 0.135, respectively.

- **Fan for airflow**

The fan provided the necessary airflow that was needed for the gasification of rice husk. The fan to be used should be capable enough to overcome the pressure exerted by the rice husk and subsequently, by the char. The fan was DC 12V-3W.

- **Ash Chamber box**

Ash chamber box was provided below the reactor chamber, which collects the ash formed in the gasifier from ash screen holder. It was provided with opening door to remove the ash. The height, width and length of ash chamber were 0.3 m, 0.5 m and 0.5 m, respectively.

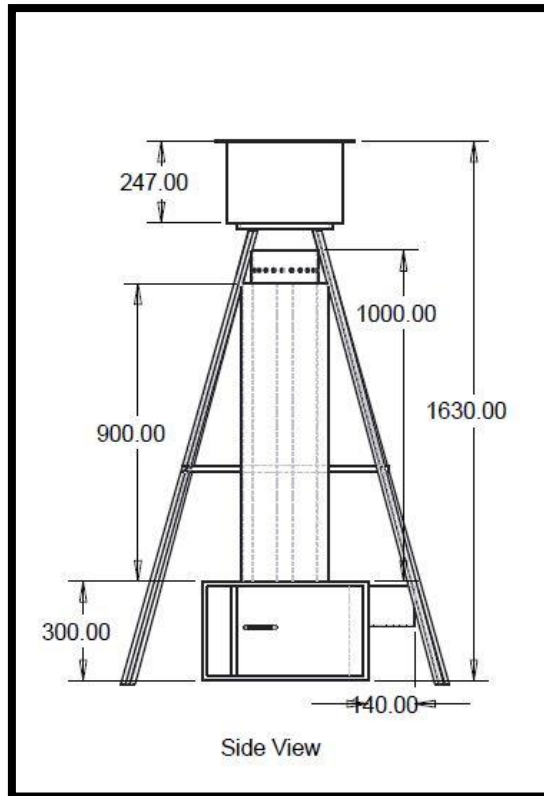


Fig.3.1 Schematic front view of developed rice husk based gasifier

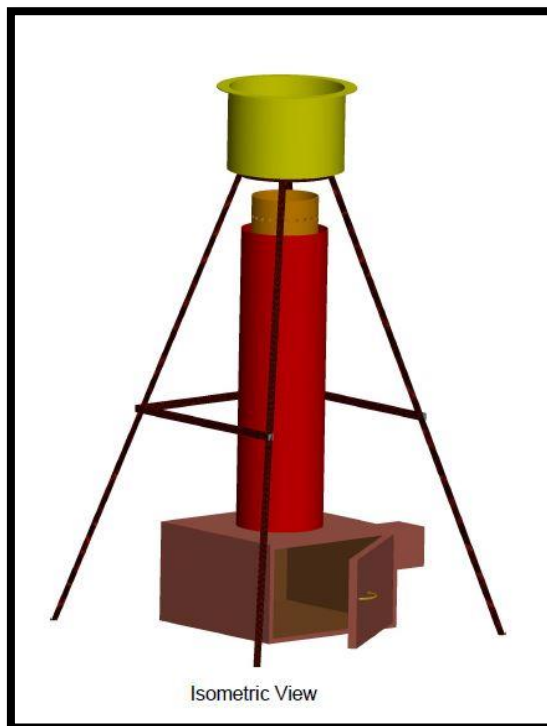


Fig.3.2 Schematic view of rice husk based gasifier

- **Stand for holding utensil**

The stand was provided to hold the utensil. The height of stand was 1.47 m and diameter of stand was 0.29 m.

- **Caster Wheels**

The wheels were welded at the bottom of gasifier for easy of transport and handling. Total four wheels were welded; two were fixed and two were adjustable at an angle 360° from adjacent.

- **Solar panel**

The solar panel was used for operating the fan which was used for airflow. The panel was mono crystalline silicon type and capacity of the panel was 10W.

- **Insulation**

The insulation between the inner and outer body used to reduce the heat losses. The insulation was a glass and used cement as binding material. The schematic view of rice husk based gasifier is shown fig 3.1 and 3.2.

The pictorial view of development of rice husk based gasifier was shown in plate-3.2, 3.3 and 3.4. The technical specifications of rice husk based gasifier were shown in Table 3.1.

3.2.5 Cost of rice husk based gasifier

The fabrication cost of rice husk based gasifier was considered as fixed cost. The fabrication cost of rice husk based gasifier involves material cost and fabrication cost. The material cost was Rs. 5810/-

Fabrication cost involves welding rods, electricity and labor charges were Rs. 1100/-The total cost of manufacturing was Rs. 6910/- (Appendix-III).

Table 3.1 Technical specification of rice husk based gasifier

Sr. No.	Particulars	Specification
1	Gasifier reactor inner diameter, m	0.2
2	Gasifier reactor outer diameter, m	0.26
3	Gasifier reactor height, m	1.0
4	Diameter of burner, m	0.2
5	Height of burner, m	0.1
6	No. of secondary air vents, no.	23
7	Height of ash chamber, m	0.3
8	Width of ash chamber, m	0.5
9	Length of ash chamber, m	0.5
10	Length of ash chamber door, m	0.42
11	Breadth of ash chamber door, m	0.022
12	Length of ash holder screen, m	0.27
13	Breadth of ash holder screen, m	0.25
14	Length of ash lever rod, m	0.53
15	Length of ash lever handle, m	0.15
16	Height of air supply fan box, m	0.14
17	Breadth of air supply fan box, m	0.13
18	Length of air supply fan box, m	0.13
19	Caster wheel, no.	4

3.3 Techno-economic evaluation of rice husk based gasifier.

The techno-economical evaluation of rice husk based gasifier for thermal application was carried out in following sub-heads, which decides the efficiency as well as economical viability of the gasifier.

- Performance of rice husk based gasifier for thermal application and
- Economic evaluation of developed rice husk based gasifier.

3.3.1 Performance of rice husk based gasifier for thermal application

The performance testing and evaluation of rice husk based gasifier for thermal application was conducted in terms of

- Laboratory tests and
- Field tests.

3.3.1.1 Laboratory testing of rice husk based gasifier

In the laboratory tests, the parameters for the rice husk based gasifier were measured. Series of tests runs were conducted to determine the operational performance of the gasifier including standard water boiling tests to determine the efficiency and the power output of the gasifier. Prior to laboratory test, proximate analysis of fuel used for gasifier was carried out (Belonio, 2005).

a. Characterization of fuel

The fuel characterization was very much important to evaluate the performance of system. The fuel used (rice husk) for gasification was characterized in term of proximate analysis and calorific value.

i. Proximate analysis

The proximate analysis (fraction of mass of moisture, volatile, ash and fixed carbon) of a sample of biomass (rice husk) was carried out using the standard analytical procedures.

The proximate analysis of rice husk was carried out using the analytical method ASTM-D- 3173 to 3175. The analysis of moisture was done before any other consideration, and it was determined by the method of oven drying (ASTM D- 3173). The samples were dried in an oven with natural

circulation of air to a temperature at 104°C till consistency of weight obtained. The quantity of ash was determined by warming the moisture free sample to 750 °C for two hr., as per ASTM D-3174. The fraction of volatile was determined by warming the sample in a crucible for 6 min to 950 °C, as per ASTM D- 3175. The fixed carbon was determined by difference.

ii. Calorific value, (Kcal/ kg)

The higher heating value of solid fuels was determined using of bomb calorimeter (ASTME- 711), where the combustion was carried out in environment with 25 atmospheric pressure of oxygen (to ensure complete combustion) saturated with steam of water (to ensure that all the water was formed in liquid). The higher calorific value of solid fuel using the bomb calorimeter experiment was determined as

$$H_{vf} = \frac{(W+w)(t_2-t_1)}{X} - E \quad \dots 3.7$$

Where,

H_{vf} = Higher calorific value of the fuel, cal/g

X = Mass of fuel placed in the crucible, g

W = Mass of water placed in the calorimeter, g

w = Water equivalent of the bomb, stirrer, thermometer, g

t₁ = Initial temperature of water in calorimeter, °C

t₂ = final temperature of water in calorimeter, °C

The proximate analysis and higher heating value of the selected fuel, rice husk (*Oriza sativa*) was determined for three samples. The average values of analysis of selected fuel for gasification are depicted in (Appendix-IV).

b. Operating parameters of rice husk based gasifier in laboratory

The various operating parameters of gasifier system were recorded to evaluate the performance of rice husk based gasifier in laboratory.

i. Start-up time, (min)

This was the time required to ignite the rice husk and consequently to produce combustible gas. It was measured from the time the burning

pieces of paper placed in the fuel until the combustible gas was produced at the burner. It was measured with the help of stop watch.

ii. Operating time, (h)

This was the duration from the time the gasifier produces a combustible gas until the end of flame from the gasifier.

iii. Total operating time, (h)

This was the duration from the time rice husk was ignited until no more combustible gas was produced in the gasifier. It was the sum of the startup time and the operating time of the gasifier.

iv. Total fuel consumption, (kg)

The fuel consumed by the gasifier for entire run-time was known as the total fuel consumption. It was measured with the help of weighing balance before the starting of the gasifier.

v. Fuel consumption rate (FCR), (kg / h)

It was the amount of fuel consumed in gasifier during the total operating time of gasifier.

vi. Specific gasification rate (SGR), (kg/ m² h)

The amount of fuel used per unit time per unit area of the reactor. This was computed using the formula, (Belonio, 2005)

$$SGR = \frac{\text{weight of fuel used (kg)}}{\text{reactor area (sq.m)} \times \text{operating time (h)}} \quad \dots 3.8$$

vii. Boiling time,(min)

The boiling time was the time taken by the water during water boiling test to reach to its boiling point.

viii. Combustion zone velocity (CZR), (m /h)

The time required for the combustion zone to move down the reactor. This was computed using the formula,

$$CZR = \frac{\text{length of reactor (m)}}{\text{operating time (h)}} \quad \dots 3.9$$

ix. Thermal efficiency, (%)

The thermal efficiency was calculated by carrying the standard water boiling test of gasifier.

The quantity of water evaporated after complete burning of fuel was determined to calculate the thermal efficiency by using formula,

$$\eta_{th} = \frac{(Mw \times Cpw \times \Delta T) + (Mu \times Cpu \times \Delta T) + (Mwe \times \lambda)}{Mfu \times Hvf} \times 100 \quad \dots 3.10$$

Where,

η_{th} = Thermal efficiency of gasifier, %

Mw = Mass of water, kg

Cpw = Specific heat of water, Kcal/kg

ΔT = Difference between initial and final temperature of water, °C

Mu = Mass of utensil, kg

Cpu = Specific heat of utensil, Kcal/kg

Mwe = Mass of water evaporated, kg

λ = Latent heat of vaporization, Kcal/kg

Mfu = Mass of fuel, kg

Hvf = Calorific value of fuel, Kcal/kg

x. Power input, (kW)

The amount of energy supplied to the gasifier based on the amount of fuel consumed was computed using the formula,

$$P_i = 0.0012 \times FCR \times H_{vf} \quad \dots 3.11$$

Where,

P_i = Power input, kW

FCR = Fuel consumption rate, kg/h

Hvf = Calorific value of fuel, Kcal/kg

xi. Power output, (kW)

The amount of energy released by the gasifier for thermal application was computed using the formula,

$$P_o = 0.0012 \times FCR \times H_{vf} \times \eta_{th} \quad \dots 3.12$$

Where,

P_o = Power output, kW

FCR = Fuel consumption rate, kg/h

Hvf = Calorific value of fuel, Kcal/kg

η_g = Gasifier efficiency, %

xii. Per cent char produced

The ratio of the amount of char produced to the amount of fuel used was computed using the formula,

$$\text{Char produced} = \frac{\text{mass of char (kg)}}{\text{mass of fuel used (kg)}} \times 100 \quad \dots 3.13$$

The operating parameters of rice husk based gasifier in laboratories were summarized in (Appendix-V and VI). The result obtained from the performance of rice husk based gasifier in terms of water boiling test was summarized in (Appendix-VII). The operating parameters and conduction of water boiling test of gasifier was shown in Plate-3.5 and 3.6.

c. Thermal profile of rice husk based gasifier

The thermal profile of the gasifier reactor was noted during the test run at rated capacity loading of the reactor. The temperature inside the reactor of the gasifier was measured by using K- type (Chromel-Alumel) digital thermometer through the top opening of reactor chamber along with the flame temperature in the burner section. The temperature at every location was measured at an interval of 10 minutes starting from the ignition of the fuel to the end of the test run.

The variation in temperature at different location in the gasifier reactor, flame and surface temperature with operating time were summarized in (Appendix-VIII). The temperature profile measurement of gasifier was shown in Plate-3.7.

3.3.1.2 Field testing of rice husk based gasifier

The field testing of newly developed rice husk based gasifier was carried out by conducting the boiling test of mango pulp at Energy Park, CAET, Dapoli in terms of following subsection.

- Boiling of mango pulp
- Fuel saving and
- Time required

a. Boiling of Mango pulp

During the boiling of Mango pulp on rice husk based gasifier the parameters tested same as parameters tested in standard water boiling test.

b. Fuel saving

It was the amount of fuel saved over the traditional method of mango pulp boiling during the field test of rice husk based gasifier. The result obtained from field testing of rice husk gasifier was summarized in (Appendix-IX). Pictorial view of field testing of rice husk based gasifier shown in Plate-3.8.

c. Time required

It was the time required for reached the boiling temperature of pulp from ignition of rice husk.

3.3.2 Economic evaluation of rice husk based gasifier.

For the success and commercialization of any technology, it is essential to know whether the technology is economically viable or not. Therefore, the economic evaluation of the developed rice husk based gasifier was carried out by considering the fuel saving per number of batch over the traditional method of mango pulp boiling and cost incurred in development system. The economics of the system carried out in terms of following indicators

- A. Fuel saving
- B. Number of batches
- C. Simple payback period

A. Fuel saving

It was the amount of fuel saved over the traditional method of mango pulp boiling during the field test of rice husk based gasifier over the traditional boiling of mango pulp. When rice husk used as fuel for Mango pulp boiling it reduces fuel cost as compare to traditional method.

B. Number of batches

It was the number of batches filled with mango pulp which were boiling of mango pulp on rice husk based gasifier over the traditional method of mango pulp boiling..

C. Simple pay-back period

It was the ratio of total saving over the traditional method to the total fabrication cost of the rice husk bases gasifier. It was calculated by using the formula,

$$\text{Simple pay-back period} = \frac{\text{Total saving over traditional method}}{\text{Total fabrication cost of rice husk based gasifier}}$$

...3.14

Calculations for newly developed system summarized in (Appendix-X)

3.4 Instrument used during study

Following instrument/equipments were used during the evaluation of the rice husk based gasifier (Table 3.2)

.Table 3.2 Instruments used during study

Sr. No.	Name of Instrument	Specification	Used for
1	Digital thermometer	Make -MECO-990 K Thermometer (Chromel-Alumel) Range: -200 to 1370°C, Accuracy: ±2%	Temperature
2	Bomb calorimeter	(1341) as per ASTM-D271-70 Energy Equivalent: 3000-10000cal / gm	Calorific value
3	Weighing balance	Make: PHONIX Capacity: 30 Kg, Accuracy: 2g	Measurement of weight
4	Electronic Balance BL series (BL220H)	Make: CONTECH Weighing capacity: 220g Accuracy: 0.001gm Stability of sensitivity: ±3 ppm/°C	Weight loss
5	Digital Stopwatch	Make: Lutron, Accuracy: 1/10 sec	Time measurement
6	Oven	Make: Quality QE-102 Temperature range: 50 - 350°C	Proximate analysis
7	Muffle furnace	Make: Quality NSW- 101, Mf-1 Temperature range: 0 - 1200°C Rating: 1.6 Kw	Proximate analysis
8	Digital Anemometer	Make : LUTRON Measurement = m/s, km/h, Operating temperature = 0°C to 50 °C Operating humidity = < 80% RH	Air flow rate
9	Infrared Thermometer	Make: HTC Model No: YI-8811 Range: -20 to 580°C, Accuracy: ±2%	Temperature

IV. RESULTS AND DISCUSSION

Energy extraction from biomass like as residues, agricultural waste, forest waste, crop waste, etc is one of the best options to manage increasing energy demand at global level. The efficient biomass utilization will also unload the pressure on limited reserve of commercial fuels. Thermal gasification is one of the established and proven processes for harnessing the biomass energy.

This chapter deals with the results obtained from the study undertaken on assessment of traditional method of mango pulp boiling, survey of mango pulp industry, development and evaluation of rice husk based gasifier. The rice husk based gasifier for thermal application was evaluated in terms of thermal efficiency and operating parameters. Thermal performance of the gasifier in terms of specific gasification rate and gasifier efficiency was determined. The economics of gasifier was studied in terms of fuel saving and number of batches.

4.1 Study of traditional methods of mango pulp boiling

The study of traditional method of mango pulp boiling was carried out at Asond near Vakavali, Tal-Dapoli. The study conducted for measuring the various parameter of mango pulp boiling process.

It was observed that all the traditional methods of Mango pulp boiling were depending upon the wood as main source for combustion. The fuel wood used for combustion was not of the particular kind i.e. the fuel was used according to the availability. The fuel was purchased from the local saw mills. The average cost of fuel was Rs. 6/- per kg.

The survey result revealed that, the capacity of mango pulp 3.6 kg per batch. The fuel required varies from 5.2 kg to 5.4 kg per batch. The time required for reached the boiling temperature of Mango pulp was 70 min. to 73 min. The boiling point of mango pulp varied from 96.6 °C to 97.1 °C.

4.2 Performance evaluation of rice husk based gasifier for thermal application

The rice husk based gasifier was evaluated to determine the various operational parameters for thermal application. The thermal profile of the gasifier reactor in two zones, zone 1 and zone 2 at different height from grate and flame temperature was evaluated. The analysis of the feedstock for the gasification was studied for the proximate analysis and calorific value estimation.

4.2.1 Properties of fuel

The air dried biomass of rice husk (*Oriza sativa*) was used as fuel for testing of gasifier system. Physical and thermal properties of fuel influence the operation of thermal system to a great extent. The physical properties include moisture content, proximate analysis and bulk density. The results obtained are mentioned in Table 4.1.

Table 4.1 Proximate analysis and calorific value of rice husk (*Oriza sativa*).

Sr. No.	Property	Value
1	Moisture content,%	10.90
2	Volatile matter,%	60.36
3	Ash content,%	10.17
4	Fixed carbon,%	18.57
5	Higher heating value, kcal kg-1	3185
6	Bulk density, kg m-3	101

The proximate analysis of the biomass rice husk (*Oriza sativa*) revealed that it was suitable fuel for gasification. It was observed that, the average moisture content of biomass was found to be 10.90 per cent. The moisture content of the fuel under study was within acceptable limit (below 15 per cent) to ensure free flow and good quality gas production.

The average volatile matter content in biomass rice husk (*Oriza sativa*) was found to be 60.36 percent. The higher amount of volatile matter revealed the suitability of fuel for gasification. Also the data indicated that, the average ash content of the biomass rice husk (*Oriza sativa*) was found to be 10.17 per cent under study. The lower amount of the ash content in the fuel under study revealed their suitability for the gasification with minimum blocking of flow of air and fuel, formation of clinkers, etc.

The most desirable component, which governed the suitability of the fuel for gasification, that the average fixed carbon was found to be 18.57 per cent in rice husk (*Oriza sativa*).

The heating value of fuel was the major factor determining the suitability of fuel for gasification. The results obtained showed that the average higher heating value was found to be 3185 kcal kg⁻¹ for biomass rice husk (*Oriza sativa*) under study.

The performance of the rice husk based gasifier was carried out by conducting two different tests namely; laboratory test and actual field test.

4.2.2 Laboratory testing of rice husk based gasifier

The laboratory test was carried out at the Department of Electrical and Other Energy Sources, College of Agricultural Engineering and Technology, Dapoli. The gasifier was tested fuel rice husk (*Oriza sativa*) for determining the performance. Parameters related to the gasifier namely; temperature at predetermined locations, consumption of feedstock and temperature of the flame produced and other operating parameters with thermal efficiency were recorded. The performance of the gasifier was analyzed under the following headings

- Operational characteristics
- Thermal efficiency by water boiling test
- Thermal profile of gasifier

4.2.2.1 Operational characteristics

The performance evaluation of rice husk based gasifier was carried out using the selected fuel, rice husk (*Oriza sativa*). The performance test runs of the gasifier were carried out by loading the gasifier reactor with rated loading capacity. The results obtained from the series of test runs for rice husk based gasifier in laboratory were shown in Table 4.2.

Table 4.2 Operational characteristics of rice husk based gasifier (Laboratory test)

Sr. No.	Parameters	Value (Avg.)
1	Start-up time, min	5.0
2	Operating time, h	1.36
3	Total operating time, h	1.41
4	Total fuel consumed, kg	3.55
5	Fuel consumption rate, kg/h	3.27
6	Ignition fuel kerosene, ml	14.6
7	SGR, kg/m ² h	100
8	CZR, m/h	0.71
9	Thermal efficiency, %	22.63
10	Power input, kW	12.49
11	Power output, kW	2.82
12	Ash produced, %	8.92

The operational characteristics showed that the average start-up time of rice husk based gasifier was 5 min and that depends on the amount of fuel (kerosene), used for ignition of rice husk (*Oriza sativa*) (charge). The average fuel used for ignition was 14.6 ml. The average operating time of fully loaded rice husk based

gasifier was found to be 1.36 h with average total operating time was 1.41 h. The average total fuel consumed during the test was found to be 3.55 kg.

Based on above results, the average specific gasification rate was determined as $100 \text{ kg m}^{-2}\text{h}^{-1}$. Based on fuel consumption and height of reactor, the average combustion zone rate was found to be 0.71 m h^{-1} . The average thermal efficiency of rice husk gasifier in laboratory was found to be 22.63 per cent. The average power input of rice husk based gasifier was found to be 12.49 kW. The average power output of rice husk based gasifier was found to be 2.82 kW. The final product of combustion i.e. ash produced was 8.92 per cent.

4.2.2.2 Thermal efficiency by water boiling test

The water boiling test of rice husk based gasifier was carried out to evaluate the thermal performance of rice husk based gasifier. The average thermal efficiency of rice husk based gasifier was found to be 22.63 per cent. The rice husk based gasifier had higher efficiency as compare to traditional method which result in fuel saving.

4.2.2.3 Thermal profile of rice husk based gasifier

The thermal profile involves three basic areas of reactor which were mentioned below

- a. Thermal profile of combustion zone
- b. Surface temperature profile
- c. Flame temperature

a. Thermal profile of combustion zone

The variation of temperature at different height from the grate of gasifier reactor and flame temperature with respect to operating time of the reactor was measured.

The thermal profile of gasifier was taken at pre-defined locations and that studied for average fuel combustion rate of 3.27 kg h^{-1} (Fig 4.1). The temperature was measured at every 10 min interval from the ignition of gasifier up to the end of

process. The gasifier was of open core, rice husk was lit-up from top. Hence the hot bed moves from top to bottom of gasifier up to the grate in to the reactor.

During initial phase of time, the temperature was higher at Zone-1 and go on decreasing up to the ambient at Zone-2.

In the Zone-1, the gradually rise in temperature from 450°C to 650°C was observed during initial 90 min of operation. The gradual decrease in temperature up to 590°C was observed in Zone-1 till 50 min of operation. The gradual decrease in temperature from upper zone during the operation of gasifier indicated the movement of char towards the grate.

In Zone-2, the gradual rise in temperature from 150°C to 800°C was observed during initial 80 min of operation. It showed that the hot bed was moved from Zone-2 to grate of reactor. The maximum temperature attend by the Zone-2 was 657°C. The gradual decrease in temperature up to 500°C was observed in 90 min of interval. The gradual decrease in temperature from Zone-2 during the operation of gasifier indicates the movement of char towards the grate.

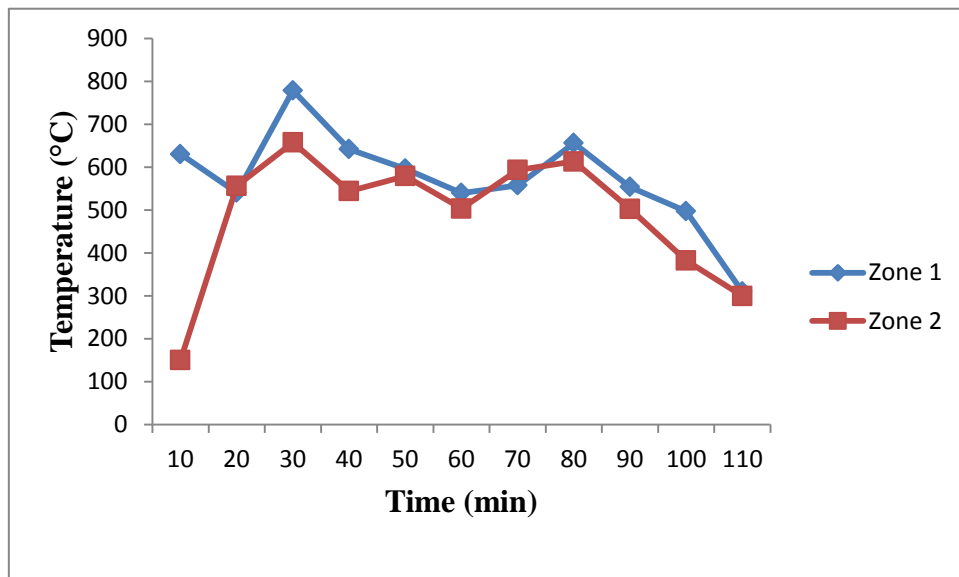


Fig: 4.1 Thermal profile of rice husk based gasifier at desired locations

b. Surface temperature profile of rice husk based gasifier

The surface temperature profile of rice husk gasifier is shown in Fig. 4.2. It was observed that the rise in average temperature from ambient to 22.6°C was achieved in 90 min of operation. The surface average temperature of rice husk based gasifier remains constant in the range of 200°C to 225.5°C till the end of the process.

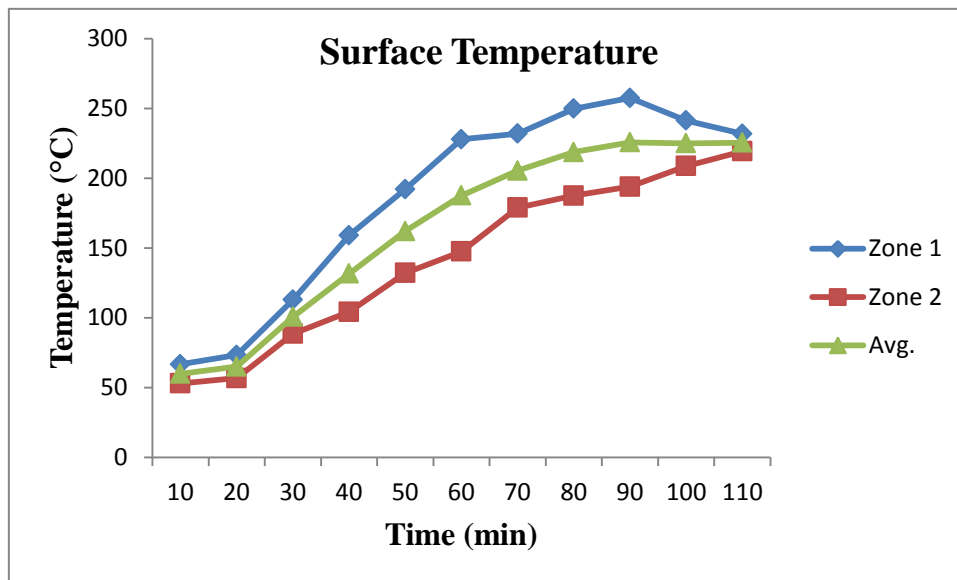


Fig: 4.2 Surface temperature profile of rice husk based gasifier

c. Flame temperature of rice husk based gasifier

The flame temperature profile of rice husk based gasifier is shown in Fig. 4.3. It was observed that the maximum temperature attained by the flame was found to be 697.7°C, which revealed that adequate amount of heat is produced for heating of Mango pulp by rice husk based gasifier.

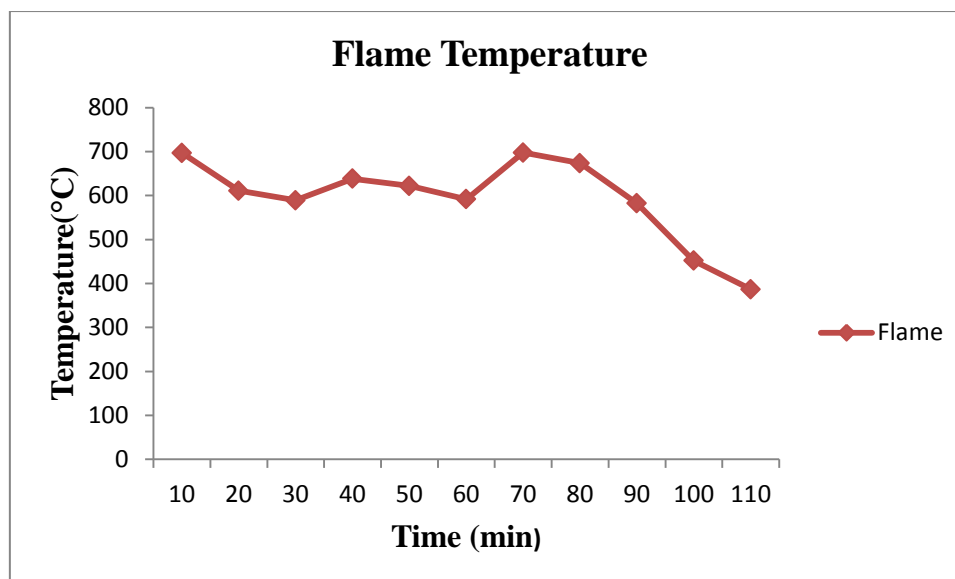


Fig: 4.3 Flame temperature of rice husk based gasifier

4.3 Field testing of rice husk based gasifier

The field test of rice husk based gasifier was carried out at the Energy Park, CAET, Dapoli. The results of operational parameters of rice husk based gasifier working in the field test summarized in Table 4.5.

Table 4.3 Operational parameter of rice husk based gasifier (Field Test)

Sr. No.	Parameters per batch	Test
1	Capacity of mango pulp boiling, (kg)	3.6
2	Start-up time, min	5
3	Operating time, min	56
4	Total operating time, min	61
5	Total fuel consumed, kg	3.52
6	Fuel saving, kg	2.1
7	Boiling point of mango pulp, °C	98.9

The field testing of rice husk based gasifier revealed that the average start-up time was found to be 5 min using the kerosene as fuel for initial ignition. The average

operating time of rice husk based gasifier for heating was found to be 56 min. and total operating time as 61min. Based on fuel consumption in rice husk based gasifier and operating time, the estimated fuel saving over the traditional method of mango pulp boiling at Energy Park, CAET, Dapoli was found 2.1 kg per batch.

4.4 Economic evaluation of rice husk based gasifier

The economic feasibility of the rice husk based gasifier was calculated and compared with the existing traditional heating system. Based on the study of the economics, the different economic parameters of the rice husk based gasifier were determined.

The amount of fuel saved over the traditional method of mango pulp boiling during the field test of rice husk based gasifier over the traditional boiling of mango pulp was determined. The average fuel saving was observed to be 2.1 kg/batch, which saved about 12.6 Rs/batch as compared to traditional fuel saved.

The number of batches filled with mango pulp which were boiling of mango pulp on rice husk based gasifier over the traditional method of mango pulp boiling was considered. Considering the two (02) batches per day, the total fuel saving was reported to be 8630 Rs/year over the traditional mango pulp boiling.

The simple payback period of the system was found to be 1.2 years which revealed that the suitability of developed system for mango pulp boiling.



Plate-3.4 Side view of developed rice husk based gasifier.



Plate-3.5 Water temperature measurement during standard water boiling test.



Plate-3.6 Standard water boiling test during laboratory testing of rice husk based gasifier.



Plate-3.2 Ash chamber box



Plate-3.3 Ash holder screen



Plate-3.7 Thermal profile test during laboratory testing of rice husk based gasifier.



Plate-3.8 Mango pulp boiling during field testing of rice husk based gasifier.



Plate-3.1 Study of traditional method of mango pulp boiling.

V. SUMMARY AND CONCLUSIONS

5.1 Summary

In India, most of the energy demand for thermal application in domestic sector is fulfilled by using abundantly available biomass. Biomass fuels and residues can be converted to energy via thermo-chemical and biological processes. Rice (*Oriza sativa*) is one of the most important food crop of India. It is the staple food of most of the people of South – East Asia. Asia accounts for about 90% and 91% of world's rice area and production respectively. At present rice husk is mostly used in small-scale boilers in process industries but these boilers do not have provision to capture fly ash and un-burnt carbon, which result in an extensive pollution being created. The rice husks consist of amorphous silica which create the problem in direct burning as well as forms the clinkers.

The thermo-chemical conversion of biomass through gasification is one of the promising routes among the renewable energy options of future energy. The biomass gasification has attracted the highest interest as it offers higher efficiencies. The producer gas produced through gasification is more versatile in its use than the original solid biomass. Gasification of rice husks has been known as one of the effective technology options for the utilization of this renewable energy resource.

The study of traditional methods of mango pulp boiling was carried at Asond near Vakavali, Tal-Dapoli. The study conducted for measuring the various parameter of mango pulp boiling process. The sample survey conducted using direct interview questionnaire regarding mango pulp boiling and measuring various temperatures by thermometer.

The fabrication of developed rice husk based gasifier was carried out at Department of Farm Machinery and Power Engineering, CAET Dapoli and the performance and evaluation of rice husk based gasifier was carried out at Department of Electrical and Other Energy Sources, CAET, Dapoli.

The assessment of traditional methods of mango pulp boiling revealed that, all the traditional methods of mango pulp boiling consists of excessive amount of wood as fuel than rice husk when gasification of biomass was done. The higher amount of

fixed carbon content (18.57 per cent), lower ash content (10.17 per cent) and higher calorific value (3185 kcal kg⁻¹) of rice husk (*Oriza sativa*) revealed its suitability for newly developed rice husk based gasifier for gasification.

The economics of developed rice husk based gasifier was carried out against the wood as fuel by using different economic indicators.

5.2 Conclusions

The performance evaluation of rice husk based gasifier system revealed that,

1. The average thermal efficiency using standard water boiling test of rice husk based gasifier was found to be 22.63 per cent using rice husk (*Oriza sativa*) as feed stock for gasification, indicates the greater conversion of fuel in to heat than the traditional methods of mango pulp boiling, with clean environment.
2. Field testing of rice husk based gasifier revealed that the saving of fuel was 2.1 kg per batch over the traditional method of mango pulp boiling.
3. The economic evaluation of rice husk based gasifier revealed that, total saving of Rs. 8430/- against the traditional method of mango pup boiling and payback period was found 1.2 years which revealed the economic feasibility for mango pulp boiling and other boiling application.

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VII. APPENDICES

APPENDIX I

Study of traditional method of mango pulp boiling at Asond near Vakavali, Tal-Dapoli.

Operational characteristics of traditional method of mango pulp boiling using fuel wood.

Sr. No.	Particular	Test 1	Test 2	Avg,
1	Capacity of mango pulp boiling, kg per batch	3.6	3.6	3.6
2	Time required for mango pulp boiling, min	70	73	71.5
3	Boiling point of mango pulp, °C	96.6	97.1	96.8
4	Fuel consumption rate, kg per batch	5.4	5.2	5.3

APPENDIX II

Design parameters of rice husk based gasifier.

1. Energy needed

$$Q_n = m \times c_p \times \Delta t$$

$$Q_n = 1 \times 0.912 \times (95^0 - 25^0)$$

$$Q_n = 63.84 \text{ Kcal/kg}$$

Actual amount of needed $[(Q_n)_{\text{actual}}]$

$$(Q_n)_{\text{actual}} = 63.84 / 0.4$$

$$(Q_n)_{\text{actual}} = 159.6 \text{ Kcal/kg}$$

$$(Q_n)_{\text{actual}} \text{ for 20 kg of pulp} = \frac{20 \times 159.6 \times 60}{30}$$

$$(Q_n)_{\text{actual}} \text{ for 20 kg of pulp} = 6384 \text{ Kcal/h}$$

2. Energy input

$$\text{FCR} = \frac{Q_n}{H_{\text{vf}} \times \eta_g}$$

$$\text{FCR} = 6384 / (3000 \times 0.65)$$

$$\text{FCR} = 3.27 \text{ kg/h}$$

3. Reactor diameter

$$D = \left(\frac{1.27 \text{ FCR}}{\text{SGR}} \right)^{0.5}$$

$$D = \left(\frac{1.27 \times 3.27}{100} \right)^{0.5}$$

$$D = 0.20 \text{ m}$$

4. Height of reactor

$$H = \frac{SGR \times t}{\rho r h}$$

$$H = \frac{100 \times 1}{100}$$

$$H = 1m$$

APPENDIX III

Fabrication cost of rice husk based gasifier.

Sr. No.	Particular	Unit	Unit Price Rs.	Total Amount Rs.
1	MS Sheet a) 18 SWG (2 mm thick)	1m(height)	1300	1300
	b) 16 SWG (3 mm thick)	0.9m(height)	700	700
2	SS Rod (6 mm Ø)	3.72m	90/m	334
3	MS Rod (6 mm Ø)	22 kg	60/m	1320
4	Caster wheels	4 no.	250/1	1000
5	Metal primer (Red oxide)	0.59	140/1	70
6	Enamel paint	0.59	260/1	130
7	Glass wool	1.5 kg	146.61/1	220
8	Cement	1.5 kg	24/1	36
9	Solar panel	1W	70	700
Total material cost				5810
9	Fabrication cost			1100
Final cost, Rs				6910

APPENDIX IV

Characterization of Rice husk (*Oriza sativa*) used for gasifier testing.

Sr. No.	Property	Method	Biomass			
			Test 1	Test 2	Test 3	Avg.
1	Moisture content, %	ASTM D-3173	10.70	11.30	10.69	10.90
2	Volatile matter, %	ASTM D-3174	61.00	60.95	59.14	60.36
3	Ash content, %	ASTM D-3175	11.10	9.91	9.49	10.17
4	Fixed carbon, %	By difference	17.20	17.84	20.68	18.57
5	Higher heating value, Kcal/kg	Bomb calorimeter ASTM E-711	3175	3025	3355	3185
6	Bulk density Kg/m ³	ASTM E870-82	101	100	103	101

APPENDIX V

Operating parameters of rice husk based gasifier.

Test 1

1. Specific gasification rate (SGR), (kg/ m² h)

$$\text{SGR} = 100 \text{ kg/m}^2\text{h (Belonio, 2005)}$$

2. Combustion zone velocity (CZR), (m /h)

$$\text{CZR} = \frac{\text{length of reactor (m)}}{\text{operating time (h)}}$$

$$\text{CZR} = \frac{1}{1.16}$$

$$\text{CZR} = 0.86 \text{ m/h}$$

3. Power input, (kW)

$$P_i = 0.0012 \times \text{FCR} \times H_{vf}$$

$$P_i = 0.0012 \times 3.27 \times 3175$$

$$P_i = 12.45 \text{ kW}$$

4. Power output, (kW)

$$P_o = 0.0012 \times \text{FCR} \times H_{vf} \times \eta_{th}$$

$$P_o = 0.0012 \times 3.27 \times 3175 \times \frac{15.62}{100}$$

$$P_o = 1.94 \text{ kW}$$

5. Per cent char produced, (%)

$$\text{Char produced} = \frac{\text{mass of char (kg)}}{\text{mass of fuel used (kg)}} \times 100$$

$$\text{Char produced} = \frac{0.308}{3.56} \times 100$$

$$\text{Char produced} = 8.65 \%$$

Test 2

1. Specific gasification rate (SGR), (kg/ m² h)

$$\text{SGR} = 100 \text{ kg/m}^2\text{h (Belonio, 2005)}$$

2. Combustion zone velocity (CZR), (m /h)

$$\text{CZR} = \frac{\text{length of reactor (m)}}{\text{operating time (h)}}$$

$$\text{CZR} = \frac{1}{1.54}$$

$$\text{CZR} = 0.64 \text{ m/h}$$

3. Power input, (kW)

$$P_i = 0.0012 \times \text{FCR} \times H_{vf}$$

$$P_i = 0.0012 \times 3.27 \times 3025$$

$$P_i = 11.87 \text{ kW}$$

4. Power output, (kW)

$$P_o = 0.0012 \times \text{FCR} \times H_{vf} \times \eta_{th}$$

$$P_o = 0.0012 \times 3.27 \times 3025 \times \frac{26.20}{100}$$

$$P_o = 3.10 \text{ kW}$$

5. Per cent char produced, (%)

$$\text{Char produced} = \frac{\text{mass of char (kg)}}{\text{mass of fuel used (kg)}} \times 100$$

$$\text{Char produced} = \frac{0.297}{3.52} \times 100$$

$$\text{Char produced} = 8.43 \%$$

Test 3

1. Specific gasification rate (SGR), (kg/ m² h)

$$\text{SGR} = 100 \text{ kg/m}^2\text{h (Belonio, 2005)}$$

2. Combustion zone velocity (CZR), (m /h)

$$\text{CZR} = \frac{\text{length of reactor (m)}}{\text{operating time (h)}}$$

$$\text{CZR} = \frac{1}{1.55}$$

$$\text{CZR} = 0.64 \text{ m/h}$$

3. Power input, (kW)

$$P_i = 0.0012 \times \text{FCR} \times H_{vf}$$

$$P_i = 0.0012 \times 3.27 \times 3355$$

$$P_i = 13.16 \text{ kW}$$

4. Power output, (kW)

$$P_o = 0.0012 \times \text{FCR} \times H_{vf} \times \eta_{th}$$

$$P_o = 0.0012 \times 3.27 \times 3355 \times \frac{26.07}{100}$$

$$P_o = 3.43 \text{ kW}$$

5. Per cent char produced, (%)

$$\text{Char produced} = \frac{\text{mass of char (kg)}}{\text{mass of fuel used (kg)}} \times 100$$

$$\text{Char produced} = \frac{0.346}{3.57} \times 100$$

$$\text{Char produced} = 9.69 \%$$

APPENDIX VI

Operational characteristics of rice husk based gasifier.

(Laboratory Test)

Sr. No.	Parameters	Values			Avg.
		Test 1	Test 2	Test 3	
1	Start-up time, min	6	4	5	5
2	Operating time, h	1.10	1.50	1.50	1.36
3	Total operating time, h	1.16	1.54	1.55	1.41
4	Total fuel consumed, kg	3.56	3.52	3.57	3.55
5	Fuel consumption rate, kg/h	3.27	3.27	3.27	3.27
6	Ignition fuel kerosene, ml	12	17	15	14.6
7	SGR, kg/m ² h	100	100	100	100
8	CZR, m/h	0.86	0.64	0.64	0.71
9	Thermal efficiency, %	15.65	26.20	26.07	22.63
10	Power input, kW	12.45	11.87	13.16	12.49
11	Power output, kW	1.94	3.10	3.43	2.82
12	Ash produced, %	8.65	8.43	9.69	8.92

APPENDIX VII

Standard water boiling test for rice husk based gasifier

Test 1

Fuel used	= Rice husk (<i>Oriza sativa</i>)
Calorific value of the fuel, Kcal/kg	= 3175
Fuel consumption rate, kg/h	= 3.27
Mass of fuel, kg	= 3.56
Specific heat of water, Kcal/kg	= 1
Volume of water before test, kg	= 5
Volume of water after test, kg	= 2.619
Time required for boiling water, min	= 37
Maximum temperature, °C	= 97.4
Mass of utensil, kg	= 0.974
Ambient temperature, °C	= 32.6
Specific heat of utensil with lid, Kcal/kg	= 0.21

Time (min)	Temperature of water (°C)
0	32.6
10	62.7
20	92.1
30	98.5
40	97.4
50	95.1
60	93.1
70	94.9

$$\eta_{th} = \frac{(M_w \times C_{pw} \times \Delta T) + (M_u \times C_{pu} \times \Delta T) + (M_{we} \times \lambda)}{M_{fu} \times H_{vf}} \times 100$$

$$\eta_{th} = \frac{(5 \times 1 \times (97.4 - 32.6)) + (0.974 \times 0.21 \times (97.4 - 32.6)) + (600 \times 2.381)}{3.56 \times 3175} \times 100$$

$$\eta_{th} = 15.62 \%$$

Test 2

Fuel used	= Rice husk (<i>Oriza sativa</i>)
Calorific value of the fuel, Kcal/kg	= 3025
Fuel consumption rate, kg/h	= 3.27
Mass of fuel, kg	= 3.52
Specific heat of water, Kcal/kg	= 1
Volume of water before test, kg	= 7
Volume of water after test, kg	= 3.108
Time required for boiling water, min	= 39
Maximum temperature, °C	= 98.3
Mass of utensil, kg	= 0.974
Ambient temperature, °C	= 33.3
Specific heat of utensil with lid, Kcal/kg	= 0.21

Time (min)	Temperature of water (°C)
0	33.3
10	42.5
20	62.2
30	96.3
40	97.6
50	97.6
60	98.3
70	96.3
80	96.6
90	96.7
100	96.7
110	96.7

$$\eta_{th} = \frac{(M_w \times C_{pw} \times \Delta T) + (M_u \times C_{pu} \times \Delta T) + (M_w e \times \lambda)}{M_{fu} \times H_{vf}} \times 100$$

$$\eta_{th} = \frac{(7 \times 1 \times (98.3 - 33.3)) + (0.974 \times 0.21 \times (98.3 - 33.3)) + (600 \times 3.892)}{3.52 \times 3025} \times 100$$

$$\eta_{th} = 26.20 \%$$

Test 3

Fuel used	= Rice husk (<i>Oriza sativa</i>)
Calorific value of the fuel, Kcal/kg	= 3355
Fuel consumption rate, kg/h	= 3.27
Mass of fuel, kg	= 3.57
Specific heat of water, Kcal/kg	= 1
Volume of water before test, kg	= 7
Volume of water after test, kg	= 2.591
Time required for boiling water, min	= 33
Maximum temperature, °C	= 98.9
Mass of utensil, kg	= 0.974
Ambient temperature, °C	= 32.6
Specific heat of utensil with lid, Kcal/kg	= 0.21

Time (min)	Temperature of water (°C)
0	32.6
10	43.2
20	61.3
30	96.9
40	97.5
50	97.6
60	97.7
70	98.9
80	98.9
90	98.9
100	98.9
110	98.9

$$\eta_{th} = \frac{(M_w \times C_{pw} \times \Delta T) + (M_u \times C_{pu} \times \Delta T) + (M_w e \times \lambda)}{M_{fu} \times H_{vf}} \times 100$$

$$\eta_{th} = \frac{(7 \times 1 \times (98.9 - 32.6)) + (0.974 \times 0.21 \times (98.9 - 32.6)) + (600 \times 4.409)}{3.57 \times 3355} \times 100$$

$$\eta_{th} = 26.07 \%$$

APPENDIX VIII

Thermal Profile of rice husk based gasifier.

Test 1

Zone 1: Upper half of

Zone 2: Lower half of

Combustion chamber

Combustion chamber

Time (min)	Temperature (°C)					
	Zone 1	Zone 2	Flame	Surface		
				Zone 1	Zone 2	Avg.
10	362.0	212.0	546.0	54.8	52.3	53.5
20	595.0	362.6	692.0	50.4	49.6	50.0
30	534.0	650.2	530.1	65.5	62.7	64.1
40	513.1	642.4	527.3	110.3	103.4	106.8
50	527.9	630.1	647.6	145.9	141.9	143.9
60	542.3	677.9	613.1	162.2	159.3	160.7
70	535.8	628.4	542.1	178.3	173.1	175.7

Test 2

Time (min)	Temperature (°C)					
	Zone 1	Zone 2	Flame	Surface		
				Zone 1	Zone 2	Avg.
10	630.2	150.5	697.1	66.7	53.1	59.9
20	540.1	556.3	611.0	73.4	56.9	65.15
30	778.5	657.2	589.1	112.9	88.6	100.7
40	641.8	543.9	638.4	159.1	104.3	131.7
50	596.3	579.1	621.9	192.1	132.1	162.1
60	539.4	503.2	591.8	227.8	147.5	187.6
70	557.2	593.1	697.7	231.9	178.9	205.4
80	655.9	612.8	673.8	249.8	187.5	218.6
90	553.8	502.7	582.4	257.4	193.9	225.6
100	497.1	381.9	452.1	241.3	208.7	225
110	309.5	299.7	386.7	231.7	219.3	225.5

APPENDIX IX

Operational characteristics of rice husk based gasifier.

(Field Test)

Sr. No.	Parameters	Test
1	Capacity of mango pulp boiling, (kg)	3.6
2	Start-up time, (min)	5
3	Operating time, (min)	56
4	Total operating time, (min) for pulp boiling	61
5	Total fuel consumption, (kg)	3.2
6	Fuel saving, (kg)	2.1
7	Boiling point of mango pulp, °C	98.9

APPENDIX X

Economic evaluation of rice husk based gasifier.

- 1) Fuel (wood) consumed in traditional method for 3.6 kg of mango pulp boiling (per batch) = 5.3 kg
- 2) Cost of fuel (wood), Rs = 6 per kg
- 3) Yearly cost of fuel (wood) per day 2 batches, Rs = $5.3 \times 2 \times 300 \times 6$
= 19080/-
- 4) Fuel (rice husk) consumed in rice husk based gasifier for 3.6 kg of mango pulp boiling (per batch) = 3.2
- 5) Cost of fuel (rice husk), Rs = 2 per kg
- 6) Yearly cost of fuel (rice husk) per day 2 batches, Rs = $3.2 \times 2 \times 300 \times 2$
= 3840/-
- 7) Overall yearly cost of fuel saving (over the traditional method of pulp boiling)
= Yearly cost of fuel (wood) - Yearly cost of fuel (wood)
= 19080 – 3840
= 15240/- Rs
- 8) Fabrication cost of rice husk based gasifier, Rs = 6910/-
- 9) Fabrication cost of traditional method, Rs = 100/-

Sr. No.	Particular	Traditional Method	Rice husk based gasifier
1	Fabrication cost, Rs	100	6910
2	Fuel consumed for 3.6 kg of mango pulp boiling, kg	5.3 (wood)	3.2 (rice husk)
3	Cost of fuel, Rs per kg	6 (wood)	2 (rice husk)
4	Yearly cost of fuel per day 2 batches, Rs	19080/-	3840/-
5	Total cost per year, Rs	19180/-	10750/-
6	Saving over traditional method, Rs	8430/-	

$$\text{Simple pay-back period} = \frac{\text{Total saving over traditional method}}{\text{Total fabrication cost of rice husk based gasifier}}$$

$$\text{Simple pay-back period} = \frac{8430}{6910}$$

Simple pay-back period = 1.2 years.

