DESIGN AND DEVELOPMENT OF UPDRAFT GASIFIER

A THESIS

BY

TAPASH KUMAR SARKAR

Examination Roll No. 10 FPM JD 05 M
Semester: January-June, 2012
Registration No.: 22333
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MASTER OF SCIENCE (M.S)
IN
FARM POWER AND MACHINERY

DEPARTMENT OF FARM POWER AND MACHINERY

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The Author

ABSTRACT

Biomass gasification is seen as an important technology component for expanding the use of biomass. Biomass from agro-residues is abundant in Bangladesh. On the basis of availability and potentiality of proper utilization of biomass, an updraft gasifier of capacity 6.3 kg coupled with stove has been designed, constructed and installed in the Farm Machinery and Postharvest Technology Division, BRRI, Gazipur. Locally available rice husk was used for gasification. Composition of producer gas was analyzed and temperature profile of reactor was also analyzed under this study. The temperature profiles and the composition of the producer gas of the gasifier have been measured at 8.20 m^3/hr air inlet velocity on the basis of equivalence ratio. The temperature ranged from 1110^0 C in the combustion zone to 110^0 C in the drying zone. The gasifier was operated in a batch mode and the air flow and gas compositions were measured. CO, the major component of the producer gas was measured 13% in the middle in the run. The temperature of the raw gas was measured about 200^0 C at outlet. Air-fuel ratio shows operation in a combustion mode at start-up, a gasification mode for the middle part of the run and a charcoal gasification mode at the end of the run. The quality producer gas was burnt in a stove. The producer gas easily cought fire and the flume showed a sustainable burning of gas.

DEDICATED

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NOMENCLATURE

BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice Research Institute
BAU	Bangladesh Agricultural University
FPM	Farm Power and Machinery
cm	Centimeter
s	second
h	hour
min	minute
t	Time
kg	Kilogram
KJ	Kilo Joule
k ton	Kilo ton
l	Liter
m	Meter
mg	milligram
MJ	Mega Joule
mm	millimeter
mt	million ton
ppm	parts per million
rpm	revaluation per minute
P_v	Velocity pressure
V	Velocity
V	Volt
A	Ampere
m_f	amount fuel
m_a	amount of air
POC	Product of combustion
m_{poc}	Amount of Product of combustion
λ	$\frac{mass\, of\ air}{mass\, of\ \ fuel}$
λ_{st}	stoichiometric ratio of $\frac{(m_a)_{st}}{m_f}$
^{0}C	Celceous
^{0}K	Kelvin
C	Carbon
H	Hydrogen
O	Oxygen
N	Nitrogen
S	Sulpher
K	Potasium
I.C.	Internal combustion
d. f.	Dilution factor
TOC	Total organic carbon
%	Percentage

CHAPTER 1

INTRODUCTION

1.1 Theory of gasification

The production of generator gas (producer gas) called gasification, is partial combustion of solid fuel (biomass) and takes place at temperatures of about 1000^0 C. The reactor is called a gasifier.

The combustion products from complete combustion of biomass generally contain nitrogen, water vapor, carbon dioxide and surplus of oxygen. However in gasification where there is a surplus of solid fuel (incomplete combustion) the products of combustion are (Figure 1.1) combustible gases like carbon monoxide (CO), Hydrogen (H_2) and traces of Methane and nonuseful products like tar and dust. The production of these gases is by reaction of water vapor and carbon dioxide through a glowing layer of charcoal. Thus the key to gasifier design is to create conditions such that a) biomass is reduced to charcoal and, b) charcoal is converted at suitable temperature to produce CO and H_2.

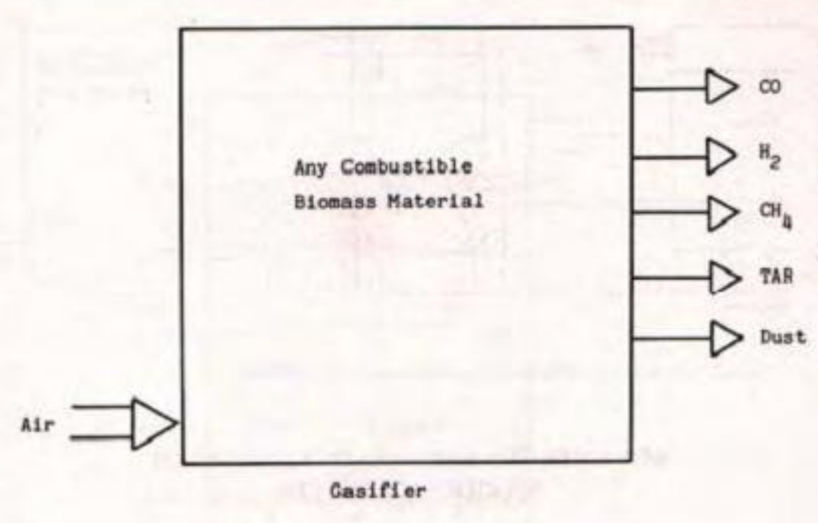


Fig. 1.1: Products of gasification

Types of Gasifiers

Since there is an interaction of air or oxygen and biomass in the gasifier, they are classified according to the way air or oxygen is introduced in it. There are three types of gasifiers (Figure 1.2); Updraft, Downdraft and Crossdraft. And as the classification implies updraft gasifier has air passing through the biomass from bottom and the combustible gases come out from the top of the gasifier. Similarly in the downdraft gasifier the air is passed from the tuyers in the downdraft direction.

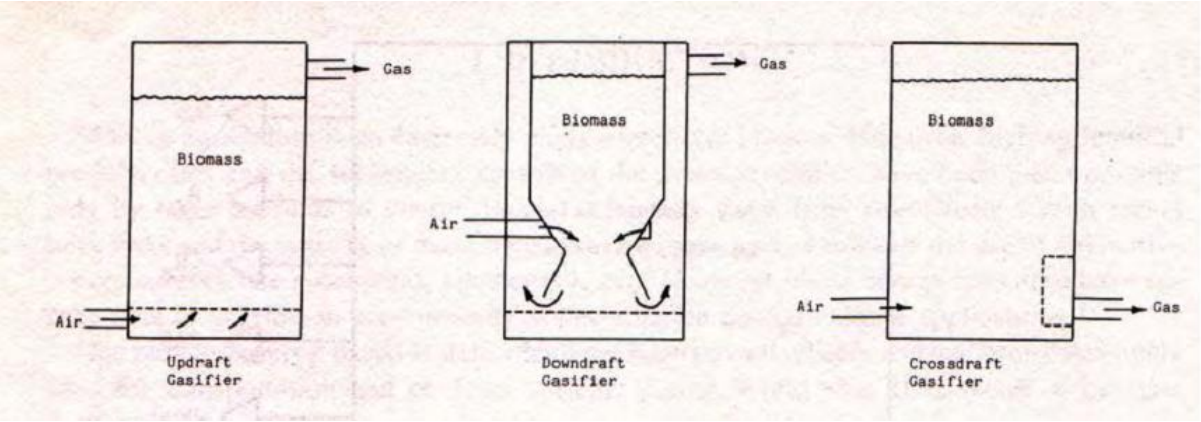


Fig. 1.2: various types of gasifier

With slight variation almost all the gasifiers fall in the above categories.

The choice of one type of gasifier over other is dictated by the fuel, its final available form, its size, moisture content and ash content (Solar Energy Research Institute (SERI). Table 1.1 lists therefore, the advantages and disadvantages generally found for various classes of gasifiers.

Table 1.1: Advantages and Disadvantages of various Gasifiers

Sl. No.	Gasifier Type	Advantage	Disadvantages
1.	Updraft	- Small pressure drop - good thermal efficiency - little tendency towards slag formation	- Great sensitivity to tar and moisture and moisture content of fuel - relatively long time required for start up of IC engine - poor reaction capability with heavy gas load
2.	Downdraft	- Flexible adaptation of gas production to load - low sensitivity to charcoal - dust and tar content of fuel	- Design tends to be tall - not feasible for very small particle size of fuel
3.	Crossdraft	- Short design height - very fast response time to load - flexible gas production	- Very high sensitivity to slag formation - high pressure drop

(Rajvanshi, A.K., 1986)

1.2. Biomass in Bangladesh

In Bangladesh, about 54.5% of total land area is used in agriculture (Islam *et al.*, 2008). Agricultural residues contribute significantly to the biomass sector. On a national basis, 98% of the total biomass energy are supplied by the agricultural crop (68%), homesteads (14%), animal dung (16%) and the remaining 2% from the reserved forest of the country (Akther, 2002).

Table 1.2: Total recoverable dry biomass from agricultural residues in Bangladesh in 2008-2009

Type of crop	**Total biomass (m ton)**	**Recoverable biomass (m ton)**	**Moisture content (%)**	**Recoverable dry biomass yield (m ton)**
			% by mass	
Field residues				
Rice straw	52.577	18.402	12.7	16.07
Wheat straw	1.265	0.443	7.5	0.41
Maize stalks	1.460	0.511	12.0	0.45
Sugarcane top	1.570	0.549	50.0	0.27
Jute stalk	2.549	0.892	9.5	0.81
Groundnut straw	0.107	0.037	12.1	0.03
Rapeseed stalk	0.305	0.107	7.5	0.10
Sesame stalk	0.043	0.015	9.5	0.01
Cotton stalk	0.014	0.005	12.0	0.00
Vegetables	0.815	0.285	20.0	0.23
Potato	1.317	0.461	12.0	0.41
Sub total	***62.021***	***21.707***		***18.789***
Processed residues				
Rice husk	9.417	9.417	10	8.48
Rice bran	3.908	3.908	9	3.56
Maize cob	0.199	0.199	15	0.17
Maize husk	0.146	0.146	11.1	0.13
Bagasse	1.518	1.518	49	0.77
Groundnut shell	0.022	0.022	8.2	0.02
Coconut husk	0.133	0.133	11	0.12
Coconut shell	0.038	0.038	8	0.03
Sub total	***15.380***	***15.380***		*13.278*
Total	***77.40***	***37.08***		***32.06***

Source: Md. Ahiduzzaman, 2011.

The traditional biomass energy is supplied from major crop residues such as rice straw and rice husk from rice plants, bagasse from sugarcane and jute stick. Some amounts of residues are produced from wheat, potato, oilseeds, spices, etc. Crop residues can be distinguished into field residues and process residues. Field residues are residues that are left in the field after harvesting and used as organic fertilizer. Process residues are generated during crop processing such as cleaning, threshing etc. These could be in the form of husk, dust and straws, etc.

The residues from cash crops like groundnut and coconut are also used to provide biomass energy. Jute stick is used for fuel purposes after being used as construction materials for rural house. It has been considered that only 35% of field crop residues can be removed without adverse effects on the future yields. For the known amounts of crop production, it may be possible to estimate the amounts of agricultural residues produced and it is given in Table 4.1. Crop processing residues; on the other hand have a 100% recovery factor (Hossain and Badr, 2007). It is estimated that a total 77.40 million tons of biomass produce annually from agricultural sector, among them recoverable amount of agricultural crop residues is 37.08 million tonnes and recoverable dry biomass yield is 32.06 million tons (Ahiduzzaman, 2011).

The principal advantages of updraft gasifier are their simple construction and high thermal efficiency: the heat of the gas produced is recovered by direct heat exchange with the entering feed, which thus is dried, preheated and pyrolysed before entering the gasification zone. Updraft gasifier is able to gasify very wet fuels. Updraft gasifier is suitable for sizes between 2 and 20 MWe. Several industrial updraft gasifiers are in operation in Northern Europe for peat as well as straw and wood chips (Mishra, 1999).

As the abundance of rice husk, has the great potential to use it for gasification and the combustible gas can be used for cooking purpose or electricity generation. Therefore, it is very important to develop an updraft gasifier that can be commercially used and become popular.

1.3. Objective

The overall objective of this study is to design and development of an updraft gasifier for production of producer gas from agricultural waste biomass for enhancement of clean energy use and improvement of energy efficiency in small scale rural area.

1.3.1. The specific objectives are as follows

1. To design of a updraft gasifier
2. To assess combustible gas from biomass

CHAPTER 2

LITERATURE REVIEW

Ningbo *et al.* (2008) conducted an investigation on the hydrogen-rich gas produced from biomass employing an updraft gasifier with a continuous biomass feeder. They set a porous ceramic reformer with the gasifier for producer gas reforming. The effects of gasifier temperature, equivalence ratio (ER), steam to biomass ratio (S/B), and porous ceramic reforming on the gas characteristic parameters were investigated. They revealed the results that the hydrogen-rich syngas with a high calorific value was produced, in the range of 8.10–13.40 MJ/Nm3, and the hydrogen yield was in the range of 45.05–135.40 g H2/kg biomass. A higher temperature favors the hydrogen production. With the increasing gasifier temperature varying from 800 to 950 ºC, the hydrogen yield increased from 74.84 to 135.4 g H_2/kg biomass. They found the low heating values first increased and then decreased with the increased ER from 0 to 0.3. A steam/biomass ratio of 2.05 was found as the optimum in the all steam gasification runs. The effect of porous ceramic reforming showed the water-soluble tar produced in the porous ceramic reforming, the conversion ratio of total organic carbon (TOC) contents is between 22.61% and 50.23%, and the hydrogen concentration obviously higher than that without porous ceramic reforming.

Verhoeven *et a*l. (2008) worked on Analysis and operation for optimization of an updraft gasifier unit. They found that biomass gasification requires an air flow of between 1.25 m3 and 2 m^3 per kg of wood. This corresponds to equivalence ratios between 0.25 and 0.4. Above this equivalence ratio, combustion takes place instead of gasification. The gas produced from the reactor has a relatively high content of tar and moisture when compared with a downdraft unit because the products of pyrolysis and drying are added to those of reduction as they flow upwards toward the reactor outlet. They recommended for more efforts should be given for better results.

Kayal *et al*. (2007) carried out an experiment on an insulated MS reactor of total length 1650 mm and constant diameter 76 mm for updraft gasification of jute stick particles with air as the gasifying agent. The results and performances had been evaluated for different sizes of jute stick panicles at various superficial air inlet velocities ranging from 0.0337 to 0.1011 m s-1 at STP. Accordingly, the superficial mass velocities of solid particles was changed from 0.0225 to 0"0950 kg/(m^2 s^1. The calorific value of the producer gas was found to be in the range of 4306-4912 kJ Sm^{-3}. An attempt was made to develop a predictive model of the gasification system. Gas diffusion through the solid pores was postulated to be controlling the rate processes in the developed non-equilibrium, mechanistic model, Approach to solve the governing equations was analytical and the total process was found to be controlled by a few dimensionless numbers containing the process variables. Comparison of experimental data and the model predictions indicated the validity of the model.

Andries *et. al.* (1996) conducted a 3-year experimental and theoretical research on co gasification of biomass and coal in a pressurized fluidized bed gasifier. Experimentally determined the influence of feedstock and operating conditions on the gasifier's characteristics. Pelletized straw and Miscanthus has been used as biomass feedstock. Experimental studies, using state-of-the-art, laboratory-scale methods have been executed by other partners in the project to determine the extent and the origins of synergistic effects and to provide background data for the assessment of the experimental results obtained from the Delft test rig. The results will be compared with the acceptability range provided by Nuovo Pignone. They were recommended to use the results of this evaluation to implement and test an optimized control strategy for operating the pressurized fluidized bed gasifier.

Jensen *et al*. (2001) has performed an experiment on the combination of thermal gasification with a Stirling engine is an interesting concept for use in small combined heat and power plants based on biomass. Combining of the two technologies a synergism can potentially be achieved. The combustion system and the geometry of the hot heat exchanger of the Stirling engine has been adapted to the use of a gas with low specific energy content and a high content of tar and particles. A demonstration plant has been built in the western part of Denmark where this Stirling engine is combined with an updraft gasifier. A mathematical simulation model has been developed as a tool to analyse a system combining the Stirling engine with a gasifier. A result from the simulation is that a net electric efficiency of 17,7 % based on the higher heating value of the biomass is obtained. They recommended for further effort is necessary for developing of updraft gasifier.

Alejandro *et a*l (2004) has implemented a project work on fixed (slow-moving) bed updraft gasification of agricultural residues. They designed and constructed a laboratory-scale countercurrent fixed-bed gasifier to produce data for process modeling and to compare the gasification characteristics of several biomasses. Densified woody biomass, birch, in form of pellets with a diameter of 8 mm and a length between 5 and 15 mm has been used as a raw material for batch autothermal gasification using air as an oxidation agent. The main objectives were to study the effect of the treatment conditions on the distribution of the products and the composition of product gas to establish the suitability of the gasifier to produce combustible gas with sufficiently high calorific value. The influence of the air flow rates on the composition of the producer gas has been studied. The amount of the biomass used in the experiments was varied between 1 and 4 kg and the flow rate of the oxidation agent, air, was varied from 1,1 to 2,6 m^3/h. They suggested for further and long term experiment is needed for precision results.

Teislev B. (2006) took an experimental work on simulation of the biomass updraft gasifier. In his experimental investigation of slow pyrolysis of thermally thick wood was carried out on commercially wood chips and wood pellets. A decrease in char yield with increasing temperature was seen. A simple model describing drying, heating and pyrolysis of wood particles with a one dimensional cylinder geometry has been developed and verified. The comparison of the one dimensional cylindrical model with pyrolysis experiments was made on both cylinders of wood and commercial wood chips. His model calculations showed that in order to obtain a good simulation of the pyrolysis for thermally thick particles in a pyrolysis reactor both internal and external heat transfer and kinetics of pyrolysis should be taken into account. They recommended for further efforts are needed for better results.

Stefano *et al*. (2009) has been developed a CFD two-dimensional model for simulating the gasification process within an air-blown updraft coal gasifier. Fixed-bed gasification processes were characterized by a complex behavioral since they involve different space- and time-dependent sub-processes where coal preheating and drying, devolatilization and char reactions take place. Simplified models, such as non-dimensional ones, useful for preliminary gross mass and energy balance, are unable to correctly simulate in detail the overall gasification phenomena and more sophisticated CFD models were required for their understanding. The complexity of the physical processes in the updraft gasifier was compounded by the multiphase nature of the flow and by the interphase processes. Considering the high volume fraction of the solid phase, close to the packing condition, the Euler-Euler approach was required to model the interpenetrating phases. The solid phase was considered as a continuum according to the kinetic theory of granular flows. The aim of this work was to characterize the spatial and time-dependent behavior of updraft gasifiers in terms of gas velocity, temperature and species concentration. In particular, the dynamic behavior of the process is fundamental to understanding the time required for complete coal conversion.

Wu *et al.* (1997) discussed the results of biomass gasification with air of the gasifier design and parameter calculation suitable for oxygen-rich gasification. The performance and advantage of wood powder gasification with oxygenrich air were analyzed in detail. Experimental data obtained from other types of biomass, such as rice hull and rice straw, were presented for comparison. Oxygen-rich air containing 85-95% oxygen is both economic and practical to produce medium heating value (MHV) fuel gas from biomass.

Hansen *et al. (*1996) performed a work for the purpose of converting straw and wood into volatile matter to be combusted in a conventional boiler, an atmospheric bubbling fluid bed pyrolysis unit has been developed. This pre-treatment is a means of supplying a major proportion of the biomass energy to the boiler without the corrosive components. Extensive testing has been carried out of the pyrolysis unit as a means of pre-treating the biomass before co-combusting straw and wood with fossil fuels in power plant boilers. The biomass is converted into two fractions: a volatile fraction for combustion in the power plant boiler and a solids fraction to be otherwise converted. Up to 90% of the energy from the input biomass is contained in the volatile fraction. The idea is to avoid feeding the corrosive alkali metals and chlorine present in the biomass into the boiler, as these cause corrosion damage to the super heater, yet still supply the boiler with most of the biomass energy. Ash is kept from biomass and the separated fossil fuels, which avoids contamination of residues.

Sohel *et al*. (2008) have conducted a study to determine the biomass fuel consumption pattern and environmental consequences of biomass fuel usage in the traditional and improve cooking stove in Bangladesh. The introduction of improved cooking stove minimizes people’s forest dependence by reducing the amount of fuel wood required to meet their household needs. In Bangladesh firewood was the most frequently used biomass fuel. It has been figured out that the incomplete combustion of biomass in the traditional cooking stove poses severe epidemiological consequences to human health and contributes to global warming. While improve cooking stove help to reduce such consequences. They suggested for further research is necessary for more reliable results.

Mamun *et al*. (2007) have worked on utilization pattern of biomass for rural energy supply in Bangladesh. The study was carried out through interviewing one hundred farmers in eight villages, under muktagachha & Trishal Upazilla of Mymensingh district during June–December, 2006 and September–October, 2007 to assess the availability and utilization pattern of crop biomass and identify the appropriate biomass energy saving technologies in rural areas of Bangladesh. The common biomasses are tree twigs, leaves, firewood, crop residues, jute sticks, rice husk, rice straw, sawdust, cowdung etc. and constitute about 60% of total energy consumption in rural households. The potential biomass availability in the study areas was about 291.47 GJ/yr-household of which the share of field crop biomass was about 229.61 GJ/yr-household. Despite the heavy demand of biomass energy in developing countries, it is utilize so inefficiently that only a small percentage of its useful energy was obtained. The overall efficiency in traditional use was only about 5-15%. They suggested that energy saving technologies should be encouraged for efficient use of available biomass in the country. They said that biogas plants, improved cooking stoves, biomass briquettes were such efficient technologies. These technologies need to be standardized and encouraged for dissemination at rural household levels in Bangladesh.

Liu H. **(**1995) has done a research work on combustion characteristics of rice husk in fluidized beds. They saw that chemical reaction kinetics of rice husk, much different from that of coals, that was obtained on the basis of thermo gravimetric experiments They were carried out with an accelerated surface area and porosimetry system to examine the microscopic structure change of rice husk. This was compared with that of coal. Combustion tests were performed on a fluidized bed combustor with a cross section of 0.2 m by 0.2 m. The proposed two-stage combustion of rice husk involves release of volatile matter and combustion of carbon separately, which was different from that of coal. The combustion characteristics of rice husk were taken into account in the design of a new boiler combining combustion styles and taking fluidized bed as the main component.

Leible and Wintzer (1996) have taken a study on comparisons between fluid and solid biofuel results of a technology assessment which was edited by Chartier, P. they have found the renewable resources in Germany have been the subject of a comprehensive technological assessment study. Various possibilities for energetic and chemical/technical use of biomass were analyzed and compared. In the field of renewable biofuels, a number of solid, fluid and gaseous fuels were included in the comparison. The emphasis of the study was product-cycle analyses, beginning with the cultivation of energy crops and ending with their energetic utilization. Furthermore, medium-term utilization prospects and their potential impacts were studied. Various technical, economic, environmental or socio-economic characteristics were deduced. Comparing fluid and solid biofuels, the solid biofuels are more favorable in energy output per ha, energy input (in % of energy output), remaining net CO_2 reduction, and subsidy requirements.

Biswas and Lucas, Energy (1997) conducted a study on economic viability of biogas technology in a Bangladesh village. The energy consumption for domestic cooking and biogas energy resources for 21 clusters of households in a village was estimated. Data were analyzed on a cluster basis, with investments shared. Under the present conditions, biogas technology would not be economically viable. Economic analysis involving viability tools including additional benefits of biogas technology indicate that creating a market for local biogas would make such a project feasible.

Rasmussen and Clausen (1995) has launched a programme for development of a coal and biomassfired CFB concept for future power plants, in order to achieve a substantial reduction of CO_2 emissions associated with energy generation. The basis of this programme is the general development of CFB technology abroad and domestic experience gained from small-scale coal and straw firing. The MIDTKRAFT Power Company operates an 80 MW,,, CFB cogeneration plant fired with a mixture of hard coal and surplus straw from farming. Straw contains much larger amounts of chlorine and potassium than normal fossil fuels, inferring a higher potential for superheater corrosion and combustor fouling. Three years of operation experience of the CFB plant is presented, including early superheater corrosion and fouling incidents, a heat surface modification and its impact on subsequent plant operation. Apart from operational experience, the results of the R&D activities executed at the Grenaa plant for further CFB development is reviewed. ELSAM has initiated a program to develop a 250 MW, CFB power plant concept, firing up to 60% biomass. USC steam conditions are adopted for the novel concept, implying an expected plant efficiency of 45%. They have given the plant operational flexibility is emphasised with a view to fulfil general power plant requirements.

Kentaro *et al*. (2011) worked on analysis of an updraft biomass gasifier with high temperature steam using a numerical model in Japan. they found that high temperature steam gasification (HTS G) was a gasification technology which utilizes super-heated steam at a temperature above 1273 K. Their paper addressed the performance analysis of an updraft HTSG gasifier using a numerical model. The experimental data was obtained from a demonstration-scale gasifier that was successfully simulated by the developed model. The calculation results showed 150–300 K temperature difference between gas phase and solid phase throughout the bed. Among a number of reactions, char gasification and water–gas shift reaction at char gasification zone played a major role to determine the syn-gas composition. Steam temperature, the ratio of steam to biomass and biomass feed rate affected the syn-gas composition while biomass particle diameter showed no significant effect. For the steam temperature and the ratio of steam to biomass, the difference of solid temperature at the bottom of gasifier determined the syn-gas composition. For biomass feed rate, the ratio of unreacted char extracted from the bottom of gasifier to supplied biomass determined the syn-gas composition.

Seggiani *et al*. (2011) conducted an experiment on sewage sludge is the residue produced by the domestic or industrial wastewaters treatment plants. The consequent need to develop alternative processes for the use of sewage sludge for energy purposes such as gasification requires experimental tests in order to quantify the potential energy recover from this waste, as well as to evaluate the optimum conditions for its gasification. In the present study, the gasification with air of dehydrated sewage sludge (20 wt.% moisture) mixed with conventional woody biomass was performed in a pilot scale updraft fixed-bed gasifier operating at atmospheric pressure.

Saravanakumar *et al*. (2011) have taken an experiment on numerical modeling of a fixed bed updraft long stick wood gasifier to evaluate the anticipated performance characteristics of an updraft fixed bed gasifier utilizing long stick wood as the source of fuel is presented. That type of gasifier was obtained high-energy release rates due to the lower inlet air velocity and extended reaction zone. The numerical model couples the performance of the individual particles and the external gas phase reactions to describe the gasifier performance. The model can describe the effect on overall system performance when conditions within the gasifier were changed, such as changes in the wood or char particle size, moisture content, gasifier height, inlet velocity, etc. The results of the model were compared with the gasifier performance for a gasifier using sticks with a 6 cm diameter, a length of 68 cm and a dry density of 600 kgm^{-3}. The model results were used to investigate the performance of the gasifier under a variety of load conditions, fuel sizes, and moisture conditions.

Saravanakumar *et al*. (2007) have presented a results of an experiment on long stick wood gasification, in an attempt to reduce wood gathering for gasification. Analyses of gasification were done using sticks with length 68 cm and diameter 6 cm. The moisture content of the wood was 25%. This top lit updraft gasifier operates with 180 W of blower power air supply to produce 9–10 kW of thermal energy, an energy yield of 50/1. Results were obtained for various flow conditions with airflow rates ranging from 25 to 45 m^3/h. For modeling, the flaming pyrolysis time for long stick wood in the gasifier was calculated to be 2.1 min. The length of the flaming pyrolysis zone and char gasification zone was found to be 37 cm and 36 cm respectively. The turn down ratio for the gasification was around 2. The rate of feed was between 9 and 10 kg/h and the gasifier operated continuously for 5 h in two runs to study the gasifier reliability. The performance studies in specific gasification rate, equivalence ratio, turn down ratio, superficial velocity, airflow, and gas flow were analyzed. Measurement of the equivalence ratio was a simple way of analyzing the behaviour of the gasifier. From the results of present investigation, it was revealed that the top lit updraft gasifier was more suitable for long stick wood as feed when compared to conventional updraft gasifier.

Murgia et *al*. (2011) have developed a comprehensive CFD model to simulate the gasification process within an air-blown updraft coal gasifier. Updraft fixed bed gasification processes were characterized by complex behavior. Simplified models, such as non-dimensional ones, useful for preliminary gross mass and energy balance, were unable to correctly simulate the overall gasification phenomena and more sophisticated approaches were required. In particular, CFD models was used to describe in a detailed way the complex time- and space dependent phenomena involved in the gasification process. Considering the high volume fraction of the solid phase, close to the packing condition, the Euler–Euler approach was required to model this multiphase flow. The solid phase was considered as continua according to the kinetic and plastic theory of granular flows. The operation of a Wellman–Galusha gasifier was investigated, considering a non-continuous loading of coal and extraction of the ash, with the aim of characterizing the space- and time-dependent behavior of the process.

Mand et *al*. (2011) have conducted an experiment on Characterization of fuel bound nitrogen in the gasification process and the staged combustion of producer gas from the updraft gasification of softwood pellets. It was derived from test runs performed with a laboratory-scale updraft fixed-bed gasifier coupled to a combustion chamber to produce data for the characterization of fixed-bed gasifier operation and to investigate the release behavior and the conversion of fuel-bound nitrogen during gasification and subsequent staged combustion of the producer gas using softwood pellets. Spatial temperature profiles and the composition of the producer gas of the gasifier have been measured for different air flow rates. In addition, the concentrations of relevant nitrogenous gas species including tars have been measured in the producer gas and at different positions in the combustion chamber. They found that the air flow rate has a significant influence on the composition of the producer gas and the temperature profile of the packed bed of the gasifier. During updraft fixed bed gasification, almost the entire fuel-bound nitrogen was released as N bound in tars from the packed bed and was then subsequently released as HCN, NO, NH_3 and N_2 as a result of tar cracking during combustion. They said that strong N-fixation in the tars was not expected and was of great relevance concerning NOx formation during combustion of the producer gas.

Mand *et al.* (2010) have worked on the modeling of an updraft fixed-bed gasifier operated with softwood pellets. Their model was a one-dimensional steady state mathematical model for the simulation of a small scale fixed-bed gasifier. The model was based on a set of differential equations describing the entire gasification process of softwood pellets and was solved by a two step iterative method. The main features of the model were homogeneous and heterogeneous combustion and gasification reactions, one-step global pyrolysis kinetics and drying, heat and mass transfer in the solid and gas phases as well as between phases, heat loss, particle movement and shrinkage within the bed. The pyrolysis model has been improved by partially cracking primary tar into lighter gases according to experimental data. The model was used to simulate a laboratory scale fixed-bed updraft gasifier. Good agreement was achieved between prediction and measurements for the axial temperature profiles and the composition of the producer gas. Moreover, results were presented for different air to fuel ratios and varying power inputs. The gasification process was improved by increasing the power input of the gasifier as a result of higher temperatures. They recommended that a higher air to fuel ratio lowers the efficiency of the gasification process.

Blasia *et al.* (2007) have discussed on supercritical water gasification (SCWG) of the wood tar fraction soluble in water. The mixture was collected downstream of an updraft wood gasification plant and presents tar compounds typical of low-temperature pyrolysis, with the highest yields attained by acetic acid, levoglucosan and 1-hydroxy-2-propanone. SCWG tests, using a laboratory-scale reactor with a plug-flow behavior, temperatures of 723–821 K, residence times of 46–114 s and initial total organic carbon (TOC) contents of 6.5–31 g/l (pressure equal to 25 MPa), show TOC conversion roughly between 30% and 70%. The corresponding yields of gas (l) with respect to the initial TOC contents (g) vary from 0.4 to 1. Gasification of TOC was well described by an irreversible, first-order, Arrhenius rate reaction with activation energy of 75.7722 kJ/mol and a pre-exponential factor of 897730 s_1. Quantification of 23 tar compounds of the product stream shows the prompt conversion of sugars and complex phenols, with the formation of intermediate products, such as furfurals, which successively decompose, and more thermally resistant species, such as acetic acid, propionic acid, 1,2-ethanediol, ketones and especially cresols and phenols.

CHAPTER 3

MATERIALS AND METHODS

3.1: Materials

The materials were used to conduct the study as follows:

- Fabrication materials: Updraft gasifier was designed using 3D AutoCAD tools. As per design gasifier was fabricated in the BRRI Research workshop using the following fabrication materials:
- MS rod, MS sheet, GI pipe, flat bar, union joint, elbo, gate valve, net, nut, bolt, blower, glass wool, fireclay etc.
- Raw materials: Rice husk was used as raw materials
- Filtering materials: Husk char, saw dust, cotton
- Measuring instruments: Different workshop tools (measuring) were used for precision fabrication of up-draft gasifier are as follows: Scale, Digital slide calipers, Tape etc.
- Scientific instruments: The following scientific instruments were used to analyze the combustible gas: Micro manometer, Air flow meter, Gas analyzer, Pyrite CO_2 indicator, K-Type thermometer with thermocouple.

3.1.1. Design consideration

During design the following points were considered:

- Availability of raw materials
- Simplicity in design
- Ease of fabrication, operations and maintenance
- Trouble free operation.

3.1.2. Assumption for design of the gasifier

Basic consideration for design:

- Air flow rate: 2.28×10^{-3} m^3/s
- Blower size: 64 mm size AC operated
- Air supply pipe: 76 mm pipe 610 mm long for convenient of installation of pitot static tube and 25 mm dia pipe 762 mm long. Reduce type taper air inlet pipe was used to increase the air velocity.
- Grate with 15 mm × 15 mm size hole and 15 mm slot made with 5 mm dia ms rod.
- 51 mm and 25 mm dia. GI pipe were use which is available in the market.
- Elbow, socket, union joint were used for assembling the gasifier unit.

3.1.3. Components of the gasifier

Gasifier unit

Batch type gasifier was designed having the holding capacity of 6.3 kg of rice husk. Two cylinders made up of 16 gage ms sheet (one inner and another outer) were used to fabricate the reactor. The reactor is called gasifier. In between two cylinders fireclay with rice husk was used as insulating material. Cover of the gasifier was attached with the help of nut-bolt and c-clamp after pouring raw materials.

Insulation material

As the inside temperature of the gasifier is very high, there is a great possibility to loss heat by convection, radiation or other process. In order to keep the loss of heat at minimum level glass wool was used as insulating material. Glass wool was attached around the outer wall of the gasifier unit in order to prevent heat loss from inside of the gasifier.

Blower

64 mm blower was used to supply air for combustion of fuel.

Grate

Grate is comprised with a net placed at the bottom of the gasifier. The fuel ash falls through the grate.

Ash collector

The ash falls through the grate retain in the ash collector.

Ash outlet

The ash is removed from the ash collector through 114 × 102 mm size outlet port.

Gas outlet pipe

Different size of pipe was used to convey the producer gas to stove.

Filter

3-stage filtering was used to purify the producer gas. It is usually cylindrical shape made of ms sheet.

Stove connection

Increase type taper outlet pipe was used to reduce the velocity and to attain pressure drop of the combustible gas and connect it to the stove.

3.1.4. Construction of the gasifier

3.1.4. 1. Gasifier reactor

The updraft gasifier comprised with two cylinders which is usually a cylindrical reactor, and forms a packed bed on the grate. The outer cylinder is 1016 mm height and 356 mm diameter and the inner cylinder is 864 mm height and 305 mm diameter made up of 2 mm thickness ms sheet. The two cylinders are fixed with the flange at the top. The top cover of the gasifier is 6 mm thickness ms sheet attached with the flange after pouring fuel material as it is a batch type gasifier. In between two cylinders fireclay with rice husk is used as insulation materials. Glass wool was also used as insulating material which was attached around the outer wall of the gasifier unit in order to prevent heat loss from inside of the gasifier reactor shown in figure 3.1, 3.2 and 3.3.

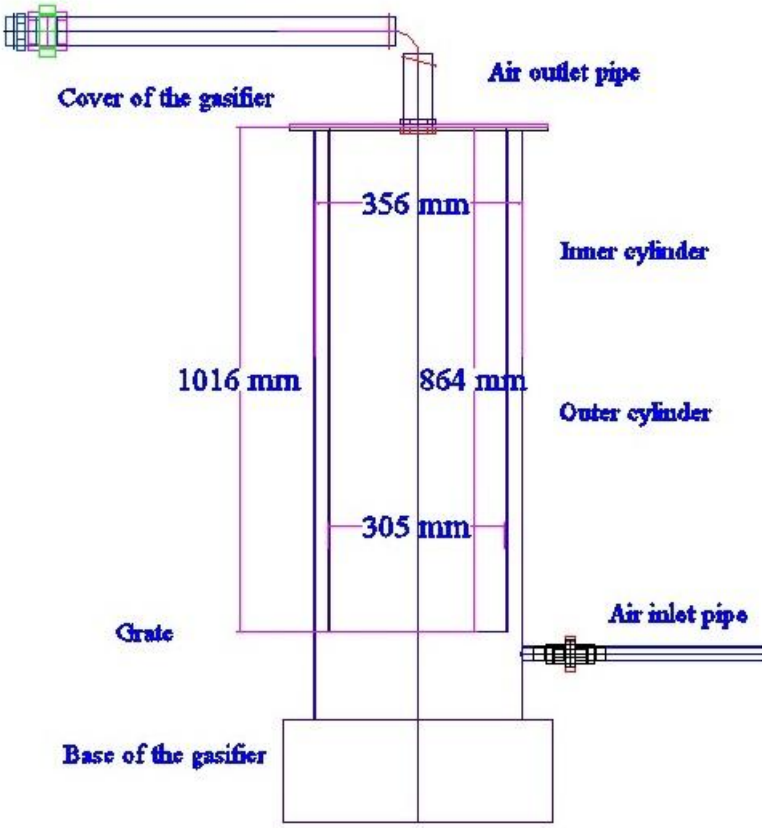


Fig.3.1: 2D view of gasifier

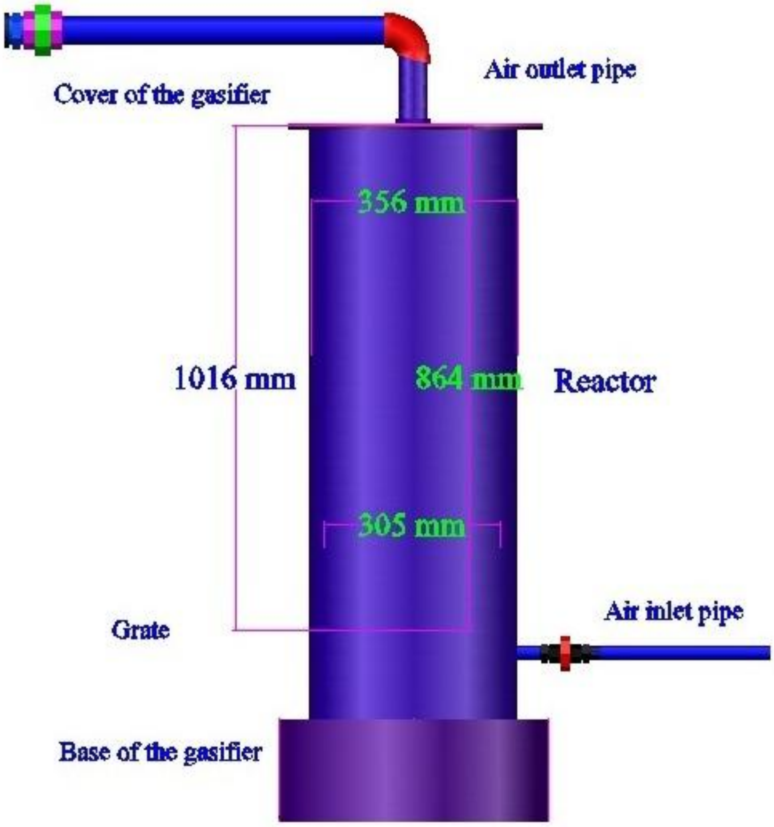


Fig. 3.2: 3D view of gasifier

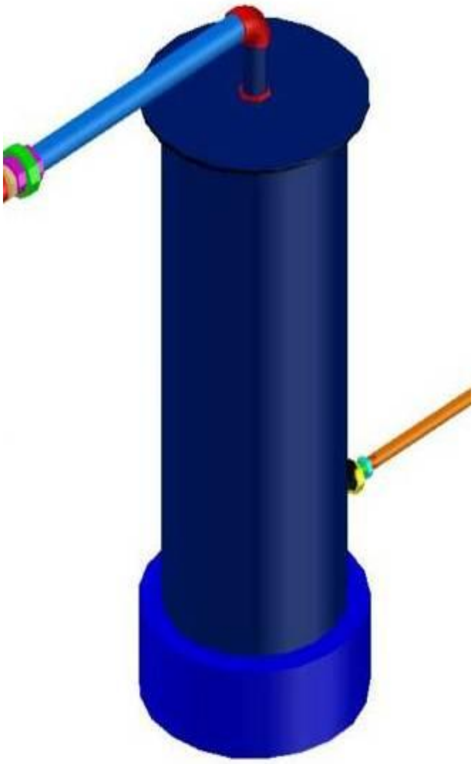


Fig.3.3: Isometric view of Gasifier

3.1.4.2. Air inlet pipe with blower

The air inlet pipe is set 76 mm above the bed of the gasifier. 76 mm pipe made by GI sheet which is reduced to 25 mm diameter by reducer attached with 25 mm dia. GI pipe in a view to increase the velocity where the Thermo-Anemometer was placed in the pipe to measure the air velocity shown in figure 3.4, 3.5 and 3.6.

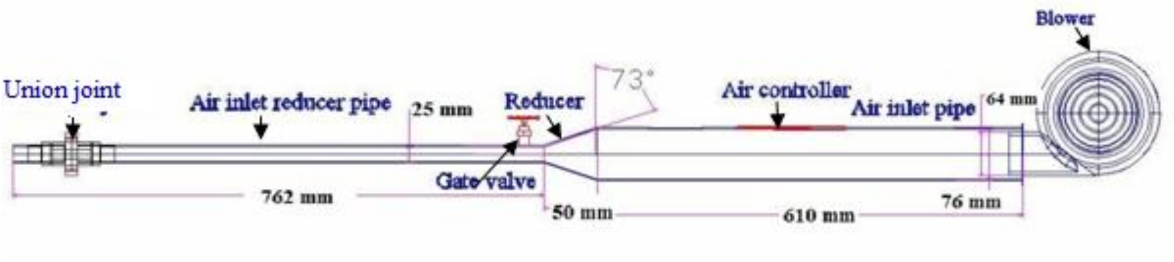
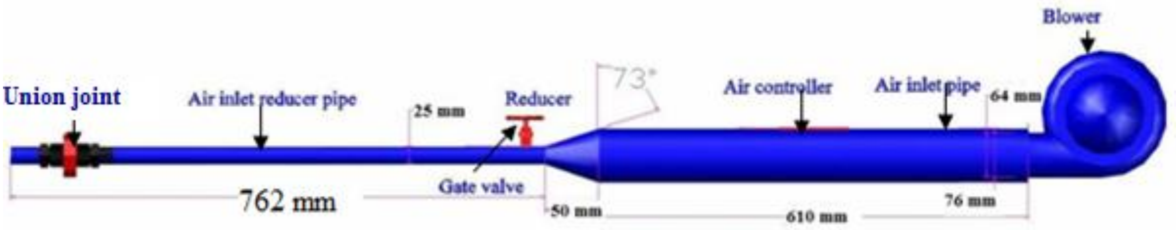


Fig.3.4: Air inlet pipe with blower



3.5: Air inlet pipe with blower

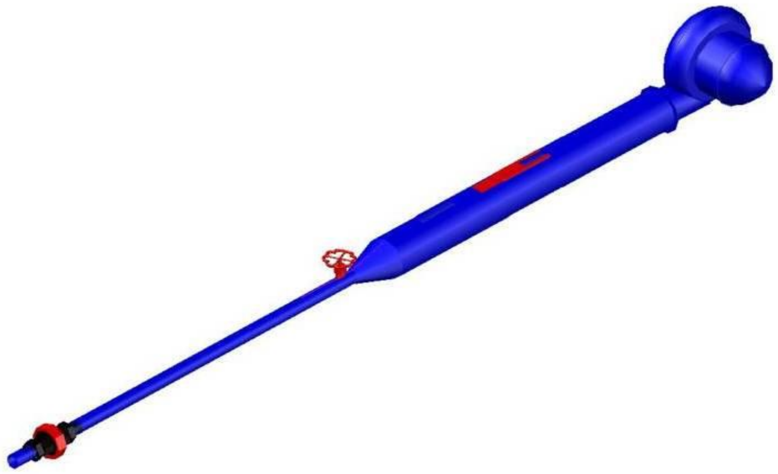


Fig.3.6: Isometric view of air inlet pipe with blower

3.1.4.3. Blower

A 54 mm AC operated blower which has 1.6A, 220V, 50/60 cycle and 3000/3000 rpm was used to supply air to the gasifier reactor shown in fig. 3.7. The gasification agent, dry or humidified air, is injected from the bottom below the grate, passes through the fuel bed and hot product gases exit the top of the gasifier at and for modified version producer gas exits 203 mm below the top of the gasifier at around 200^0 C. This size of blower was used as it is available in the market.

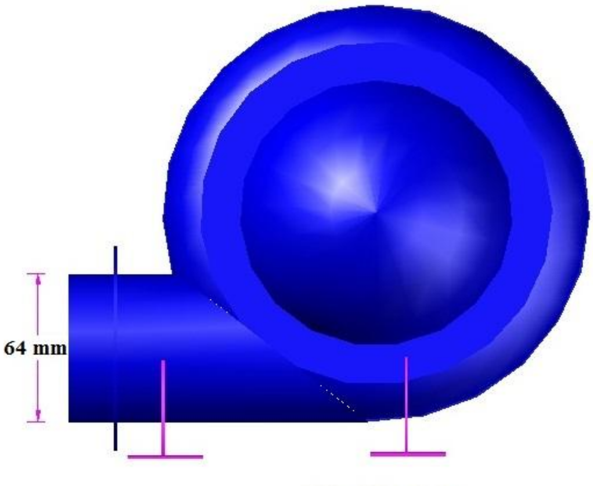


Fig.3.7: Blower

3.1.4.4. Gate valve

Gate valve was used in the air inlet pipe to control the air flow and to supply the measured amount of fresh air in the gasifier reactor for incmplete combustion in the reactor, therefore, proper reaction in the whole process takes place. 25 mm gate valve was placed in the reducer pipe fig. 3.8. Additionally a sliding device was provided in the 76 mm pipe to control the supply of air. The size of the sliding device is 76 mm × 25 mm.

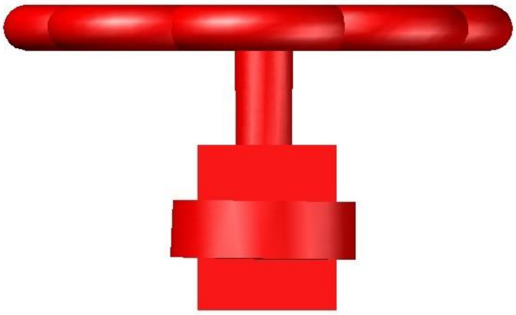


Fig.3.8: Gate valve

3.1.4.5 Grate

Grate is comprised with a perforated plate of 15 mm × 15 mm hole size placed at the bottom of the gasifier which is act as air distributor. Virtually the fuel materials set burning on the grate and form a packed bed over it. The fuel ash after combustion falls through the grate and retain in the ash collector. Also 15 mm slot size plate made up of 5 mm dia. MS rod was considered according to the physical properties of ash of rice husk. Each rod was placed 15 mm apart from others shown in figure 3.9, 3.1.0 and 3.1.1. Two plate will be used at grate and finally one of two will be selected which one performed better. As ash removal from updraft gasifier is little bit difficult, therefore, grate design and selection is more important. Rice husk contains higher degree of ash compared wood, therefore ash removal is very much important for use of high ash contained material.

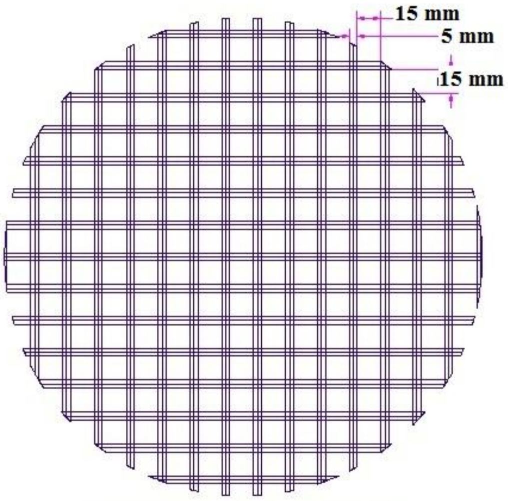


Fig.3.9: Square type grate

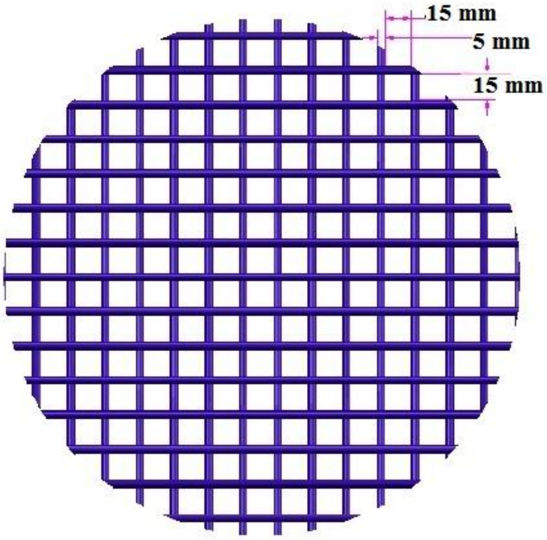


Fig.3.1.0: Square type grate

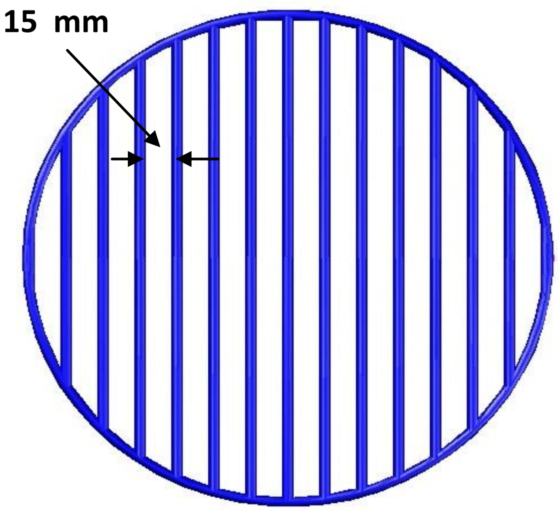


Fig.3.1.1: Final version of slot type grate

3.1.4.6. Ash collector and ash outlet

The fuel ash from the reactor falls through the grate keep stacking in the ash collector. The size of ash collector is 305 mm diameter and 152 mm height. An ash outlet port of size 114 × 102 mm is used to dispose the ash from the collector.

3.1.4.7. Gas outlet pipe and stove connection

The producer gas comes out through the outlet pipe of 51 mm diameter from the top of the gasifier and for modified version 203 mm below the top of the gasifier. At initial stage this gas contain higher amount of water vapour, tars and traces of higher hydrocarbons. To remove tar and water vapour the gas outlet pipe is connect to the filters. From the third and final filter a 51 mm diameter pipe was used as outlet pipe to deliver the dry gas to the stove.

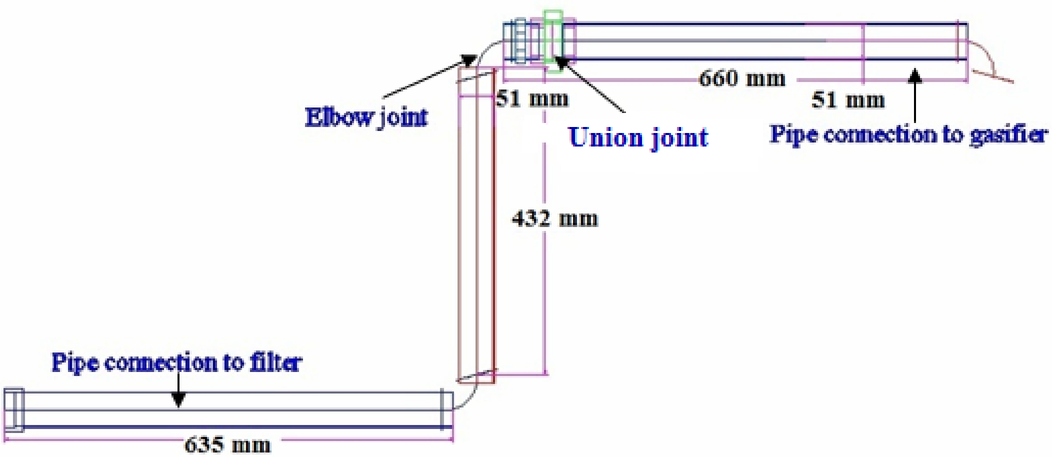


Fig.3.1.2: Pipe to connect gasifier and filter

An increase type taper was used to connect the stove. The gas exit delivery pipe is 216 mm diameter. Taper size of pipe used to attain certain pressure drop and to reduce the velocity as well. Elbo and universal joint was used to join the pipe and to carry the producer gas to the desired point figure 3.1.2 and 3.1.3.

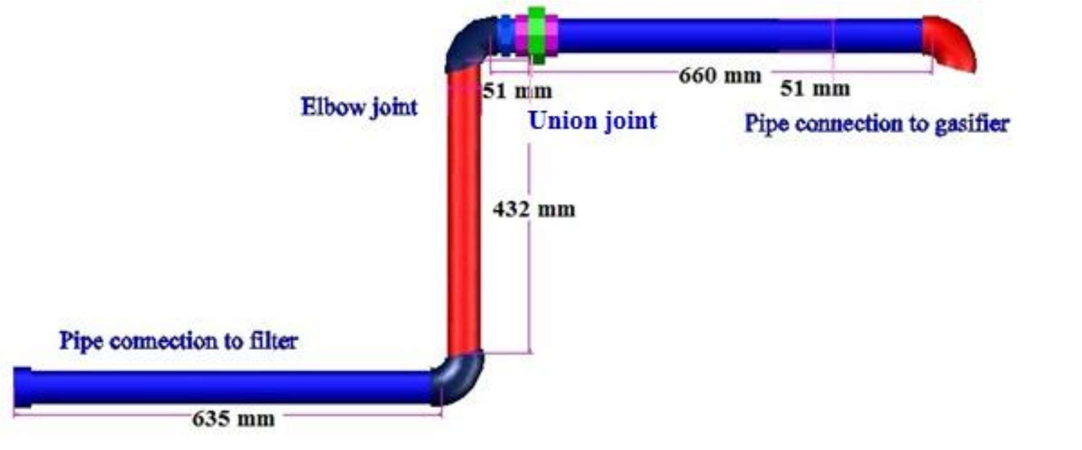


Fig.3.1.3: Gasifier and gas filter connection pipe

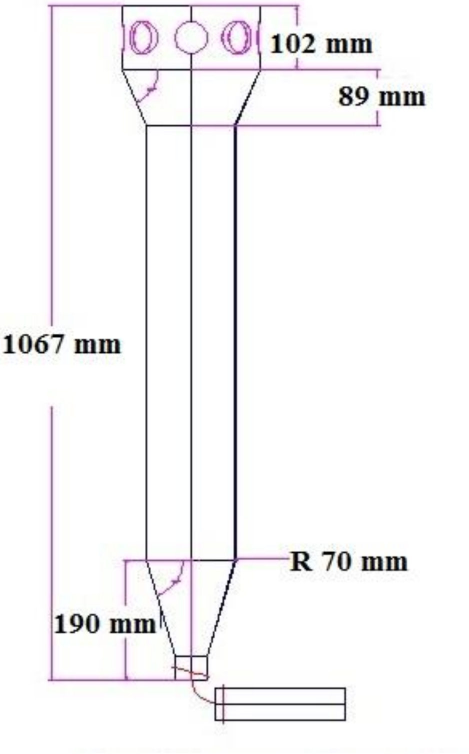


Fig.3.1.4: Chimney of the Gasifier

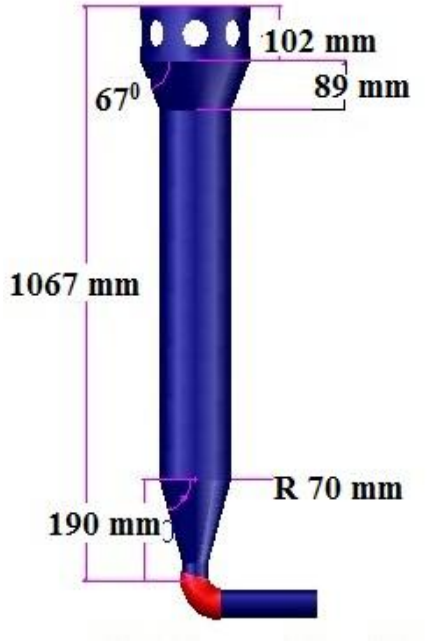


Fig.3.1.5: Chimney of the gasifier

3.1.4.8. Filter

Three filters are used in series connection. The filter is cylindrical in shape and the size of each cylinder is 203 mm diameter and 381 mm height. The lower part of the cylinder is tapered and reduced to 13 mm where a nut is attached figure 3.1.6, 3.1.7 and 3.1.8. The taper portion of the cylinder is 76 mm, where tar and moisture set down that finally drain out through controlling nut.

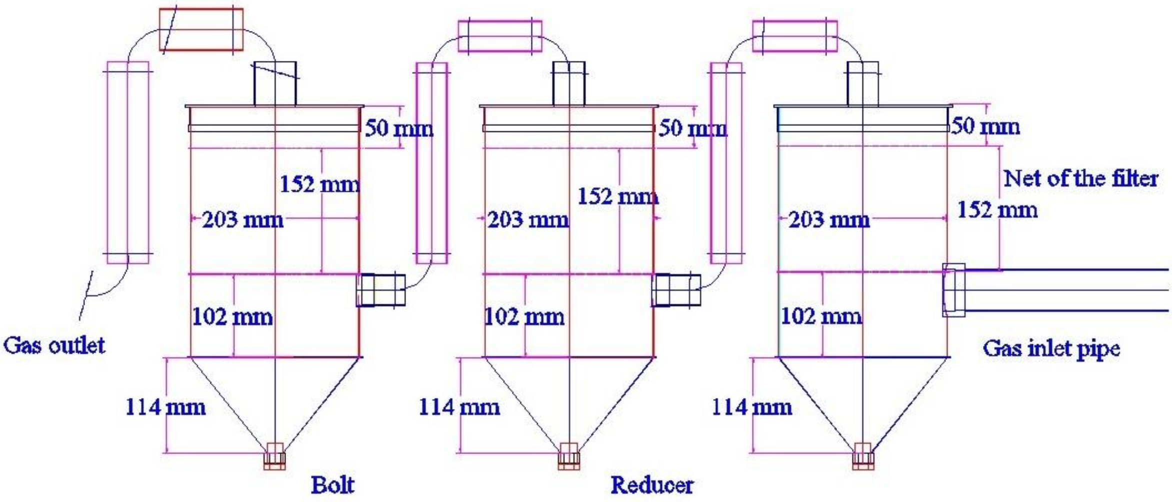


Fig3.1.6: Filter of the gasifier connected in series

The first filter is elementary one. Rice husk char is used as primary filtering material. The maximum portion of tar and moisture are removed from here. In the second filter sawdust is used as secondary filtering material. Sawdust is fine filtering material and here the producer gas is tar free. Finally the gas pass through the third filter filled with cotton as filtering material. Maximum moisture removes at this stage and the gas get dry which is used for heating purpose.

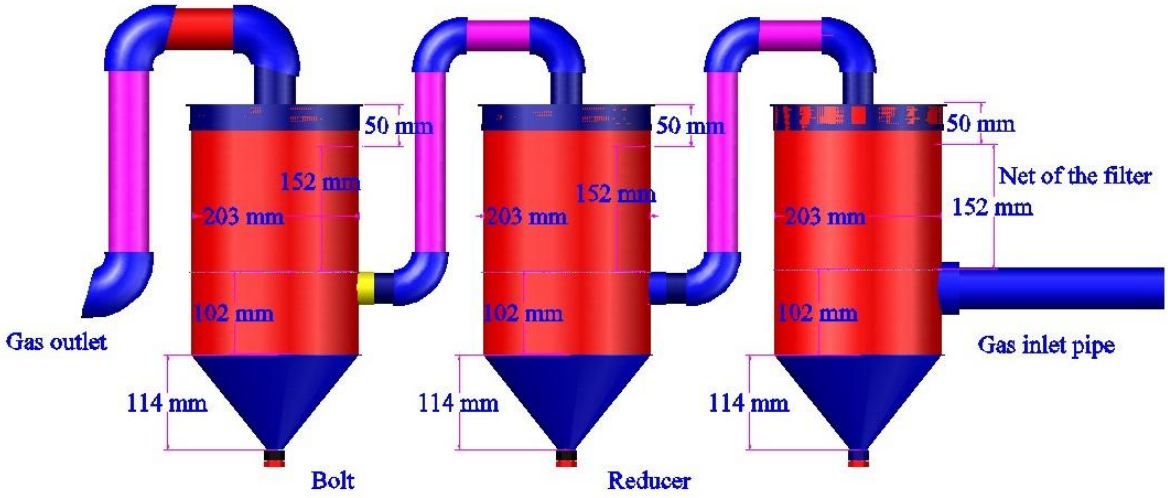


Fig.3.1.7: 3D view of filter connected in series

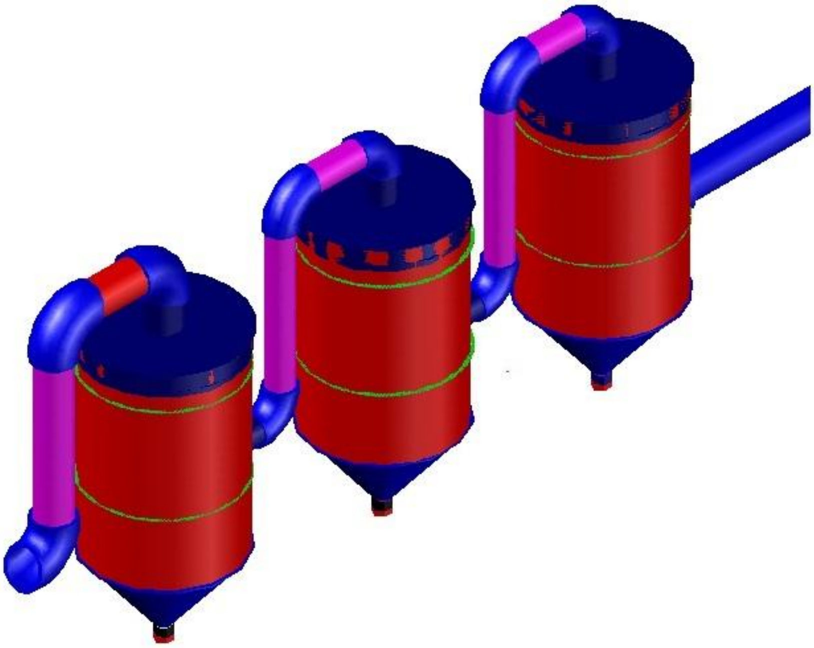


Fig.3.1.8: Isometric view of filter

3.1.4.9. Net:

Six nets of similar hole size used in the three consecutive filters. The hole size of each net is 2 mm diameter fig.3.1.9. In each filter two nets are placed at 152 mm distance apart from each other. Lower net is placed 178 mm above the bottom of the cylinder and another one is placed 152 mm above the first one. The nets were arranged in the three filters in similar way. The filtering materials are retaining in between the two nets. Small hole size nets were used so that fine filtering material cannot be blown or come out with the combustible gas.

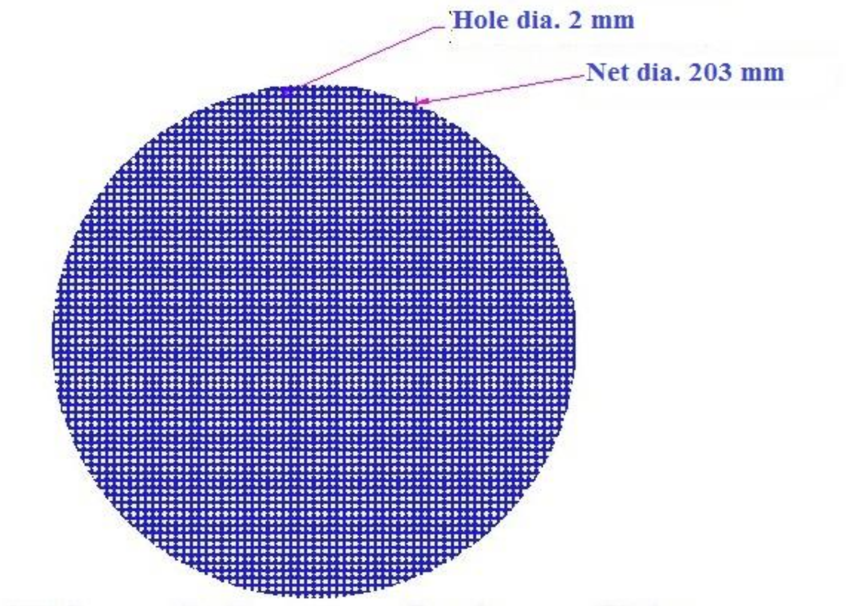


Fig.3.1.9 Net of the filter

3.1.5.0. Complete design of the updraft gasifier:

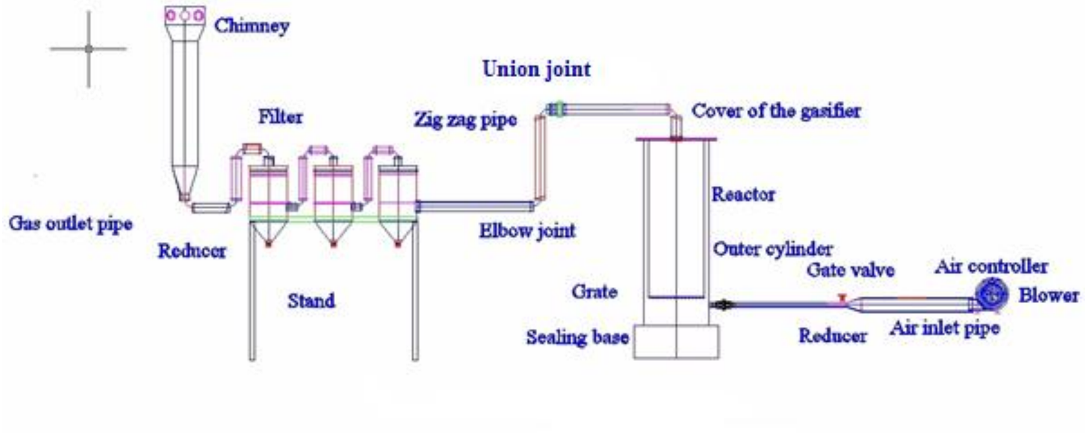


Fig.3.2.0: Design view of updraft gasifier

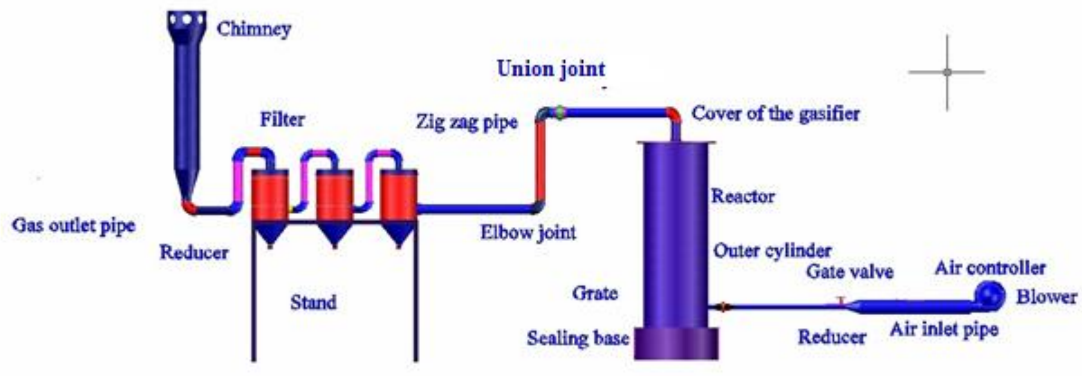


Fig.3.2.1: Front view of updraft Gasifier (3D)

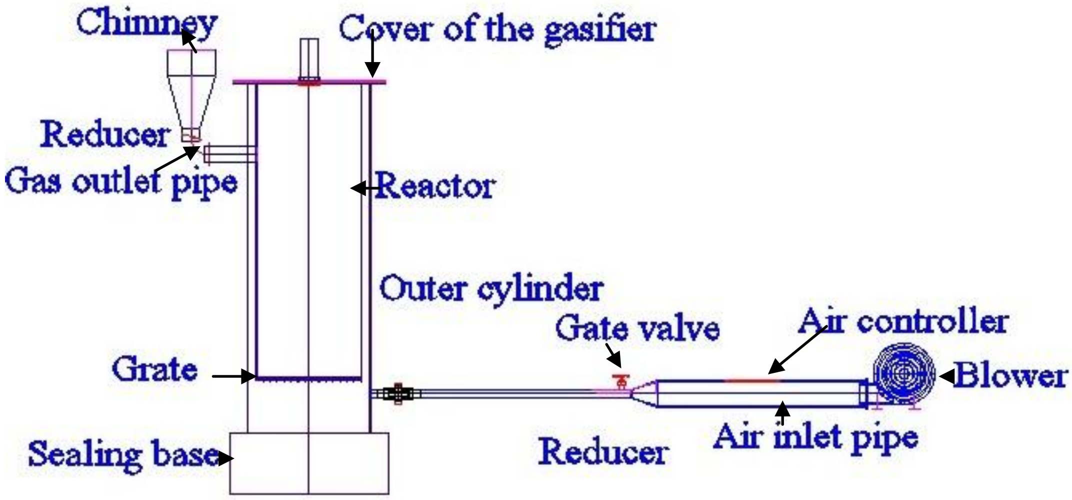


Fig.3.2.2: Modified version of updraft Gasifier

3.1.5.1. Scientific instrument used in the experiment

3.1.5.1.1. Micro manometer (Mark 4 – Testing set):

The Mark 4 Testing Set is used to measure the inlet air velocity incorporates two adjustable

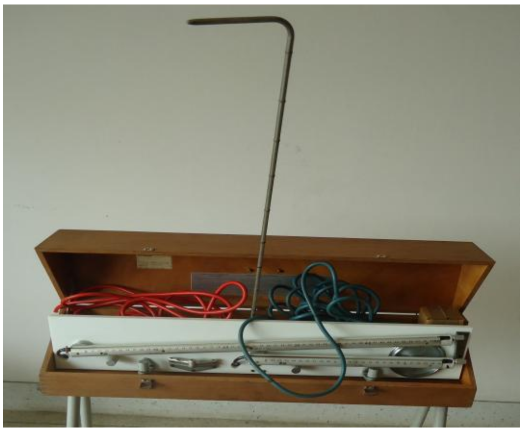


Fig.3.2.3: Micro manometer

limb manometers which cover the ranges of 0-10 in. w.g. and 0-20 in. w.g. and only give direct readings when in the vertical position. Both gages may be used for positive, negative or differential readings.

3.1.5.1. 2. *Heavy Duty Hot Wire CFM Thermo-Anemometer*

Heavy Duty Hot Wire CFM Thermo-Anemometer, Model 407119A use to measure the velocity of air ranging from 0.2 to 17.0 m/s or 40 to 3346 ft/min.

Fig.3.2.4: Heavy Duty Hot Wire CFM Thermo-Anemometer

3.1.5.1.3. Bacharach Fyrite® Gas Analyzers

Bacharach Fyrite Gas Analyzers are fast, accurate and easy to use instruments for measuring and analyzing carbon dioxide or oxygen. Analyzers are used for either CO2 or O2 analysis.

Fig.3.2.5: Bacharach Fyrite® Gas Analyzers

Fyrite indicators have a broad range; they may be exposed to ambient temperatures from -34° to 65°C (-30° to 150°F), and gases up to 450°C (850°F) may be tested with standard aspirator sampling equipment. 0.1 N potassium hydroxide (KOH) is used as reagent for measuring CO2 in the producer gas.

3.1.5.1.4 DEELTA 65^{-3}

Gas-Analyzer

Gas-Analyzer was used to measure CO and O_2 in the producer gas. Using this analyzer CO can be measured up to 10,000 ppm and O_2 Can be measured up to 21%.

Fig.3.2.6: Delta 65^{-3} Gas Analyzer

3.1.5.1.5. Thermometer with thermocouple

The thermocouple is installed in the gasifier through a port on the top of the gasifier. Temperatures of the different zones inside the gasifier are measured by using thermocouple. The probe is inserted into the reactor and placed at different height where the temperature is recorded.

Fig.3.2.7: Thermometer with thermocouple

3.2: Methodology

3.2.1. Working principle of gasifier

Gasification

The updraft gasifier is the oldest and simplest form of fixed-bed gasifiers. It can handle biomass fuels with high ash (up to 15%) and high moisture content (up to 50%) (Olofs son *et al.* 2005). It is more robust than other fixed bed gasifiers because it is less sensitive to variations in size and quality of biomass. In an updraft gasifier, the biomass fuel is fed continuously from the top of the gasifier, which is usually a cylindrical reactor, and forms a packed bed on the grate. The gasification agent, dry or humidified air, is injected from the bottom below the grate, passes through the fuel bed and hot product gases exit the gasifier at the top at around 420-570 K. The overall gasifica-tion process can be separated into four different reaction zones, stratified along the reactor height.

3.2.2. Reaction chemistry and temperature profile of the gasifier

The following major reactions take place in combustion and reduction zone (SERI, 1939-1945).

1. Combustion zone

The combustible substance of a solid fuel is usually composed of elements carbon, hydrogen and oxygen. In complete combustion carbon dioxide is obtained from carbon in fuel and water is obtained from the hydrogen, usually as steam. The combustion reaction is exothermic and yields a theoretical oxidation temperature of 1450^0 C (Schapfer and Tobler, 1937). The main reactions, therefore, are:

$$C + O_2 = CO_2 \quad (+\ 393\ \text{MJ/kg mole}) \qquad (1)$$

$$2H_2 + O_2 = 2H_2O \quad (-\ 242\ \text{MJ/kg mole}) \qquad (2)$$

2. Reaction zone

The products of partial combustion (water, carbon dioxide and uncombusted partially cracked pyrolysis products) now pass through a red-hot charcoal bed where the following reduction reactions take place (SERI, 1939-1945).

$$C + CO_2 = 2CO \quad (-\ 164.9\ \text{MJ/kg mole}) \qquad (3)$$

$$C + H_2O = CO + H_2 \quad (-\ 122.6\ \text{MJ/kg mole}) \qquad (4)$$

$$CO + H_2O = CO_2 + H_2 \quad (+\ 42\ \text{MJ/kg mole}) \qquad (5)$$

$$C + 2H_2 = CH_4 \quad (+\ 75\ \text{MJ/kg mole}) \qquad (6)$$

$$CO_2 + H_2 = CO + H_2O \quad (-\ 42.3\ \text{MJ/kg mole}) \qquad (7)$$

Reactions (3) and (4) are main reduction reactions and being endothermic have the capability of reducing gas temperature. Consequently the temperatures in the reduction zone are normally 800-1000^0 C. Lower the reduction zone temperature (~ 700-800^0 C), lower is the calorific value of gas.

3. Pyrolysis zone

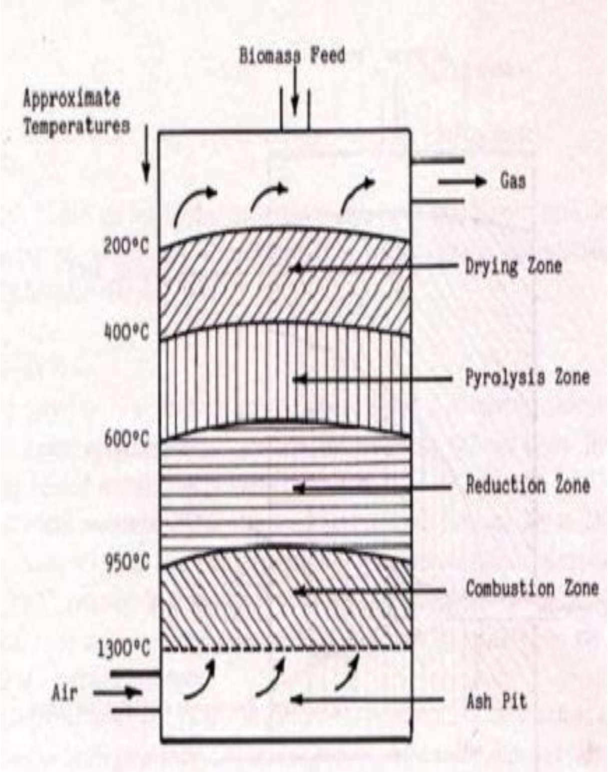
Wood pyrolysis is an intricate process that is still not completely understood (Schapfer and Tobler, 1937). The products depend upon temperature, pressure, residence time and heat losses. However following general remarks can be made about them.

Up to the temperature of 200^0 C only water is driven off. Between 200 to 280^0 C carbon dioxide, acetic acid and water are given off. The real pyrolysis, which takes place between 280 to 500^0 C, produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between 500 to 700^0 C the gas production is small and contains hydrogen.

Thus it is easy to see that updraft gasifier will produce much more tar than downdraft one. In downdraft gasifier the tars have to go through combustion and reduction zone and are partially broken down. Since majority of fuels like wood and biomass residue do have large quantities of tar, downdraft gasifier is preferred over others. Indeed majority of gasifiers, both in World War II and presently are of downdraft type.

Finally in the drying zone the main process is of drying of wood. Wood entering the gasifier has moisture content of 10-30%. Various experiments on different gasifiers in different conditions have shown that on an average the condensate formed is 6-10% of the weight of gasified wood (Schapfer and Tobler, 1937). Some organic acids also come out during the drying process. These acids give rise to corrosion of gasifiers.

The temperature profile of the updraft gasifier is shown in the figure below:



Source: Book (Alternative Energy in Agriculture)

Fig.3.2.8: Approximate temperature in the updraft gasifier

3.2.3. Experimental procedure

As per design a prototype of gasifier unit was fabricated in the Farm Machinery and Postharvest Technology Division Research Workshop of Bangladesh Rice Research Institute. The gasifier was installed in the drying laboratory of the division. After installation series of runs were done. First of all empty run (without rice husk) was done in order to make sure whether it performs properly and if there was any leakage. Both water sealing and without water sealing techniques were practiced. The gasifier unit was placed in a water pan to make it air tight. In other case the gasifier was placed on a sealing base and sealed with clay material. While the air flowing through the gasifier both the gate valve and the sliding device for controlling the air flow were open. Sun dried rice husk was used as gasification material. Proximate analysis of rice husk was done in the laboratory. The experiment was conducted under 100% loading conditions. After loading rice husk in the reactor, the top cover of the reactor was sealed with the help of nut and bolt and c-clamp. To measure the air velocity, the pitot tube was placed in the air inlet pipe while the gasifier in operation to measure the velocity of air supplied to the reactor. Also Heavy Duty Hot Wire CFM Thermo-Anemometer was used to measure the air velocity. Heavy Duty Hot Wire CFM Thermo-Anemometer was also used to measure the gas velocity at the outlet pipe. To start combustion of rice husk in the reactor, broken chips of briquette were fired on the grate. When the briquette has got enough energy to torch rice husk the measured amount of rice husk was poured into the gasifier and covering plate was placed on the top of the gasifier fixed with nut-bolt and clamp to make it leak proof. At full load conditions the total time of each operation was measured and at 20 minute interval the properties of the producer gas was measured. Thermocouple was placed through a hole at the top of the gasifier into the gasifier to measure the temperatures at different layers. The gate valve and sliding device were used to control the air velocity. At different air velocity the composition of producer gas was measured. While the gasifier was in operation the combustible gas comes out through outlet pipe placed at the top of the gasifier and passes through the three consecutive filters to remove tar and water vapor. The gas sample was collected from the outlet pipe of the filter for analysis. The temperature of the exhaust gas was measured. As the gas temperature was much lower and the percentage of CO was not much higher, a simple modification was made with the gasifier. The outlet pipe was fitted 8 inches below from the top of the gasifier. A stove was coupled with the outlet pipe of 5 inch length. After starting the gasifier at 20 minutes interval different data were taken. A series of runs at full loading condition were done and different data were taken. Data were collected:

- Air velocity at inlet pipe
- Temperature at different zones of the gasifier
- CO in the producer gas
- CO_2 in the gas content
- O_2 in the producer gas

Flow chart diagram of gasification system is as follows:

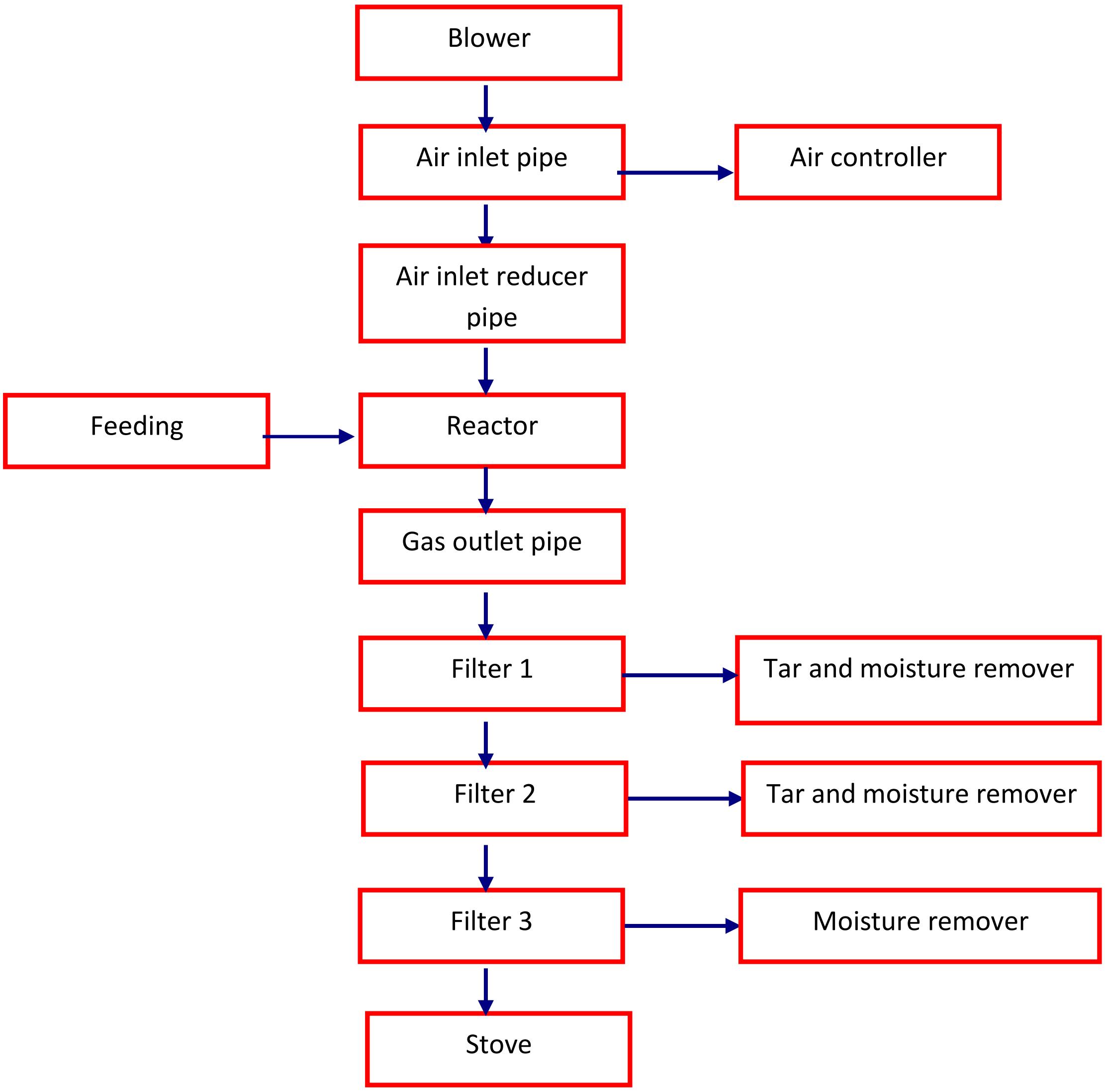


Fig.3.2.9: Flow chart diagram of gasification system

3.2.4 Assessment of biomass in Bangladesh

Biomass is used as fuel in the gasifier. Present status of biomass fuel in Bangldesh was assessed from secondary data from books, journal, report etc. under the study. Performance of the gasifier was conducted using rice husk as feedstock.

3.2.5 Physical characterization of rice husk

3.4.5.1 Determination of Moisture Content

To determine the moisture content of a sample tests were performed by the oven-drying method. Approximately 20 g of a test sample was measured into a clean, oven-dried, pre-weighed crucible. This initial mass of sample and crucible were recorded as W_w. Sample was dried in an oven preset to 105°C ±3°C for 2 (two) hours. The dry mass of crucible and sample was measured as W_d after cooling in a desiccators for approximately five (5) minutes. The percent moisture of sample on a dry basis was calculated as

$$M_d = \frac{Ww}{W_d} \times 100 \qquad (3.1)$$

Where,

M_d = Moisture content in dry basis (%)

W_w= weight of moisture (g)

W_d= weight of dry matter (g)

3.4.5.2 Determination of Bulk density

The bulk densities of samples were determined by cylindrical container which is best suited the quantities of test samples available were chosen. To determine the volume of a test container, the pre-weighed container was filled with water (at room temperature) until maximum capacity. The mass of water plus the container was measured. The volume of the container was calculated from the net weight of water and the density of water (1000 kg/m^3).

A pre-weighed cylindrical was filled with test sample (Size 1 cm, except rice husk) and dropped from a height of 15 cm on to a horizontal wooden surface. The sample material in the container was topped until the maximum capacity was reached. Surplus material was leveled off with a wooden scantling and pieces which extended above the top of the cylinder were sheared off with a pair of garden shears before weighing, instead of pulling them out and refilling until maximum capacity. The container and sample were weighed, and net mass of material was divided by the volume of container to obtain the bulk density as follows:

$$P_b = \frac{F - W}{V} \qquad (3.2)$$

Where P_b is the bulk density of the sample (kg/m^3), F is the weight of the container and sample (kg), W is the weight of the container (kg), and V is the volume of the container (m^3).

3.2.6 Proximate Analysis

Proximate analysis was performed for the rice husk samples to determine the weight fractions of volatile, ash and fixed carbon contents. As yet no universally accepted test standards specific to biomass material exist, and thus the standards developed for coal is used here (BS

1016).To determine volatile 1 gm of dried sample (approx.) of each type of sample was taken in a closed silicon crucible. The crucible has a special design having ground silicon cover (Tatlock brand). The volatile matter was determined by heating the sample at 900°C for 7 (seven) minutes in muffle furnace as per standard BS 1016. The weight loss of matter, after adjustment of free moisture, was treated as the volatile matter. The mass remaining in the crucible, minus the mass of ash, is termed fixed carbon. The ash content was determined by incineration at 815°C for 2 hours in air of the sample of biomass material (BSI, 1973).

3.2.7 Air fuel ratio for gasification

On an average 1 kg of biomass produces about 2.5 m^3 of producer gas at S.T.P. In this process it consumes about 1.5 m^3 of air for combustion (Schapfer *et al.*, 1937). For complete combustion of wood about 4.5 m^3 of air is required. Thus biomass gasification consumes about 33% of theoretical stoichiometric ratio for wood burning.

All fossil fuels contain combustible and incombustible components (also known as diluents)
Fossil fuel

Combustible components	Incombustible or diluents
Solid fuels: C,S,H	N,O, ash and moisture
Liquid fuels C,H,S	N,O
Gaseous fuels H_2, CO	N_2, CO_2, O_2, SO_2, hydrocarbons, NH_3 and H_2S

In the table C is carbon, S is sulphur, H is hydrogen, N is nitrogen, O is oxygen. Note that in the solid fuels they are present in the elemental form.

Combustion is a fast chemical reaction between combustible component(s) and an oxidizing agent. Mostly air is used for combustion. Dry air contains 21% O_2 and 79% N_2 and so 1 mole of O_2 carries with it 3.76 moles of N_2. Combustion equations with air, when complete combustion takes place are

$$C + (O_2 + 3.76\ N_2) = CO_2 + 3.76\ N_2 \qquad (1)$$

$$S + (O_2 + 3.76\ N_2) = SO_2 + 3.76\ N_2 \qquad (2)$$

$$H_2 + \frac{1}{2}(O_2 + 3.76\ N_2) = H_2O + 1.88\ N_2 \qquad (3)$$

$$CH_4 + 2\ (O_2 + 3.76\ N_2) = CO_2 + 2H_2O + 7.52\ N_2 \qquad (4)$$

Similarly, for other hydrocarbons combustion reactions can be written. Note that complete combustion refers to conversion of C, S, H_2 or CH_4 into CO_2, SO_2 and H_2O.

Objective of combustion is to attain complete combustion with stoichiometric amount of air required in equations 1 to 4. Complete combustion is also termed as perfect combustion.

3.2.7.1: Stoichiometric amount of air

Theoretically complete combustion can be obtained when stoichiometric amount of air used. Stoichiometric amount (also termed theoretical air or air for complete combustion) of air can be calculated by considering the products of combustion obtained on complete combustion. In general any balanced chemical equation (mole input = moles output) can be used to calcula te stoichiometric amount of air.

In combustion equations 1 to 4, we note that 1mole of C requires 1 mole of O2 or 4.76 moles of air to give 1 mole of CO_2 and 3.76 moles of N_2. Similarly 1 mole of H_2 requires $\frac{1}{2}$ mole of O_2 or 2.38 moles of air to give 1 mole H_2O and 1.88 mole of N_2.
Let us calculate stoichiometric amount of air for combustion of rice husk of composition of C=48.88%, H=5.52%, O=44%, 10% moisture content per kg of rice husk.

$$C = \frac{48.8}{12} = 4.07,\ H = \frac{5}{1} = 5,\ O = \frac{44}{16} = 2.75$$

Chemical formula = $C_{4.07}H_5O_{2.75} = C_8H_{10}O_5$

Total weight = (12 × 8 + 10 +16 × 5) = 186

Chemical reaction with air for complete combustion of rice husk

$$3(C_8H_{10}O_5 + H_2O) + 24(O_2 + 3.78N_2) \xrightarrow{Complete\ combustion} 24CO_2 + 18H_2O + 24 \times 3.78\ N_2$$

Weight of husk = 186 × 3 = 558 unit

Weight of air = 24 (32 + 3.78 × 28) = 3308.16

Air : Husk =3308 : 558 = 5.93 : 1

For complete combustion of 6.3 kg of rice husk, the amount of air would be

5.93 × 6.3 = 37.35 kg

3.2.7.2: Actual amount of air supplied for gasification

Diameter of inlet pipe = 1 inch = $(0.0254)^2$ m

Velocity of air, V =4.5 m/s

$$\text{Therefore, Area of the inlet pipe, } A = \frac{\pi \times (0.0254)2}{4}$$

$$= 5.067 \times 10^{-4}\ m^2$$

Therefore, quantity of air supplied, $Q = AV = 4.5 \times 5.067 \times 10^{-}4 = 2.28 \times 10^{-3}\ m^3/s$

$$= 2.28 \times 10^{-3} \times 3600$$

$$= 8.20\ m^3/hr$$

Quantity of rice husk per batch = 6.3 kg

Total running time = 1 hr

$\therefore$ Air supplied for gasification = 8.20 × 1 = 8.20 m^3

We know that density of air is 1.2 kg/ m^3

$\therefore$ Amount of air supplied = 8.20 × 1.2 = 9.84 kg

Stoichiometric amount of air required for 6.3 kg rice husk = 37.35 kg

For a given type of fuel, air fuel ratio controls the combustion and amount of products of combustion (POC)

Consider combustion of fuel of amount m_f with air m_a which produces POC m_{poc}

$$m_f + m_a = m_{poc}$$

$$\frac{m_{poc}}{m_f} = 1 + \frac{m_a}{m_f}$$

Let, $\lambda = \frac{m_a}{m_f} = \frac{mass\,of\ air}{mass\,of\ fuel}$

λ_{st} = stoichiometric ratio of $\frac{(m_a)_{st}}{m_f}$ when m_f is constant

$\frac{\lambda}{\lambda_{st}} = K = \frac{m_a}{(m_a)_{st}}$; $(m_a)_{st}$ = stoichiometric amount of air

$$\frac{m_{poc}}{m_f} = 1 + \lambda_{st}.K$$

From the above calculation

Equivalance ratio, (ER) $\frac{\lambda}{\lambda_{st}} = \frac{m_a}{(m_a)_{st}} = \frac{9.84}{37.35} = K = 0.27$

Here, $K < 1$ which means $\lambda < \lambda_{st}$ or $m_a < (m_a)_{st}$ this situation leads to incomplete combustion. POC will contain CO, smoke dust besides CO_2, N_2 etc.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Physical Properties of Agricultural Biomass

4.1.1. Moisture Content

Moisture content is one of the main criteria for the selection of energy conversion process technology. Thermal conversion technology such as direct combustion, gasification etc. requires biomass fuels with low moisture content, while those with high moisture content are more appropriate for biological-based process such as fermentation or anaerobic digestion (Garivait *et al.*, 2006). On the other hand, the moisture content of biomass fuel affects the heating value of producer gas. In thermal conversion processes, it is important to reduce the moisture content of biomass fuel. High moisture contents contribute to low gas heating value. This is because, dry biomass burns at higher temperature and thermal efficiency than wet biomass. High moisture contents will reduce the thermal efficiency since the heat is used for drying purpose (Miskum, 2006). Thus a dry fuel material is preferred for combustion, but on the other hand a certain amount of moisture in the fuel is beneficial for gasification (Ghaly *et al.*, 1989). The average moisture content percentage of BRRI dhan28 and BRRI dhan50 is found 8.95 for this study. The moisture content of some agricultural biomasses range from 5% - 60% and is given in Table 4.2.

Table 4.1: Moisture content (%) of some selected agricultural biomass

Agricultural biomass	% Moisture content	References
Rice husk	8.95	Measured
Rice husk	8.68-10.44	Mansaray and Ghaly, 1997
Rice Straw	12-22	Strehler et al., 1987
Wheat Straw	12-22	Strehler et al., 1987
Jute stick	5-10	Asadullah et al., 2008
Sugarcane bagasse	40-60	Strehler et al., 1987
Water hyacinth	8-52	Davies et al., 2011

4.1.2. Bulk Density

Bulk density is defined as the weight per unit volume of a material, expressed in kilograms per cubic meter (kg/m^3) or pounds per cubic foot (lb/ft^3) (Ragland *et al.*, 1991). Bulk density is directly influenced by moisture content, shape and form of the material. To know actual data of bulk density it is important for determining costs of transport and storage and the design of handling and conveying system. Besides, in order to design combustion chambers and furnaces efficiently bulk density data is needed (Tariq *et al.*, 1994). The average bulk density of BRRi dhan28 and BRRI dhan 50 is found 100.03 kg/m^3 under this study. The bulk density of some agricultural biomasses range from 11-160 kg/m^3 and is given in Table 4.3.

Table 4.2: Bulk density (%) of some selected agricultural biomass

Agricultural biomass	Bulk density (kg/m^3)	References
Rice husk	100.03	Measured
Rice husk	86-114	Mansaray and Ghaly, 1997
Rice Straw (LP Size 10-170 mm)	11-121	Susawa and Sasaya, 1985
Wheat Straw	44-67	Susawa and Sasaya, 1985
Jute stick	110	Asadullah et al., 2008
Sugar cane bagasse	112-160	Susawa, 1989
Water hyacinth	48-303	Davies et al., 2011

LP= loosely piled

4.1.3. Proximate Analysis of Rice Husk

Proximate analysis is used to determine the percentage of volatile matter, fixed carbon and ash in fuel. The proximate contents give an indication of flaming and glowing combustion resulting from gas phase combustion of volatile matter and combustion of the solid char (ROSSI, 1984). As yet no universally accepted test standards specific to biomass material exists, and reliance is generally made on standards developed for coal. The ash content provides a measure of the combustible mineral matter in the fuel. To determine the volatile matter, 1 gram of dried sample (approx.) of each type of rice husk was taken in a closed silicon crucible. The crucible has a special design having ground silicon cover (Tatlock brand). The volatile matter was determined by heating the sample at 900^0 C for 7 minutes as per standard BSEN 1860-2:2005 (BRITISH STANDARD, 1860). The weight loss of matter, after adjustment for free moisture, was treated as the volatile matter. The mass remaining in the crucible, minus the mass of ash, is termed as fixed carbon. The ash content was determined by incineration at 815^0 C for 2 hours, in air, of sample of biomass material (Tariq *et al.*, 19944 and Rees et al. 1957). The results of proximate analysis are shown in Fig.4.1. The volatile mater of 2 husk varieties viz. BRRI dhan28 and BRRI dhan50 is of 61.90 to 62.84%. Fixed carbon of two varieties is 15.92 and 15.09. The higest fixed carbon is found in BRRI dhan28 and lowest in BRRI dhan50 variety.

(Iyer *et al*. 1977) reported the volatile matter of rice husk from different location varies from 65% to 67% while the fixed carbon and ash content varied from 11.2% to 18% and from 13.1% to 22.4% respectively. (Kargbo *et al*. 2009) reported that the volatile matter of rice husk is 63.52%. These results are in close proximity to the results of this study. The slight variation that has been observed is due to the fact of the physical properties of biomass frequently depends of the soil and geographical location of biomass produced.

Ash content of these two varieties are 22.17 and 22.06% respectively. The variation of ash content plays an important role in obtaining the energy from rice husk. It also directs the design of boiler furnace grate as well as gasifier.

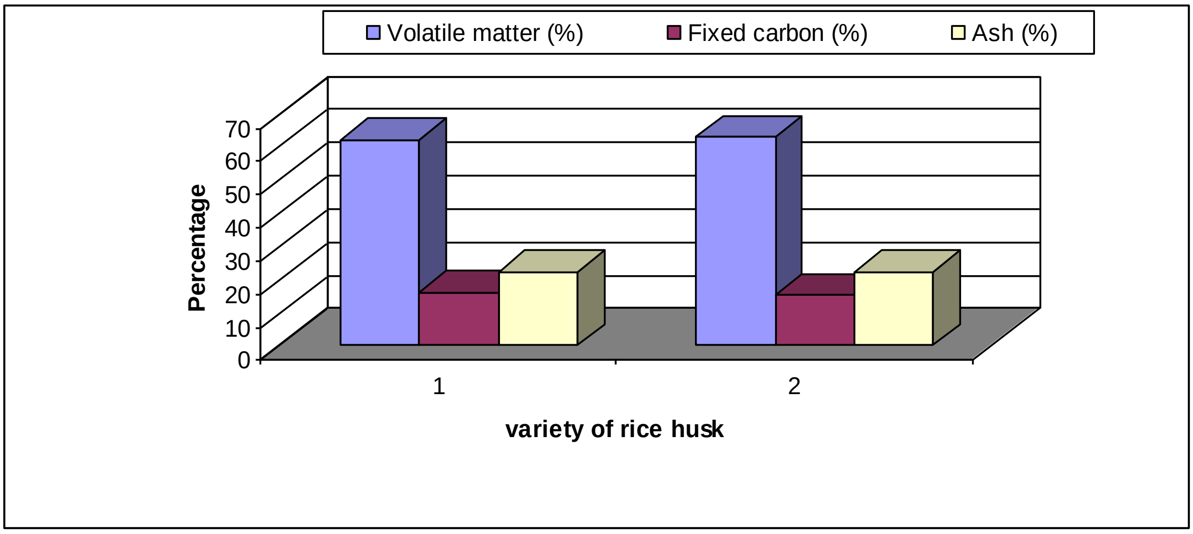


Fig.4.1: Proximate analysis of different varieties of rice husk

4.1.4. Ultimate analysis of rice husk

Ultimate analysis determines chemical composition fuels in terms of carbon, hydrogen, oxygen, nitrogen and sulphur as mass percentage of dry and ash free (daf) biomass material. This basis for reporting of ultimate analysis and gross calorific value has the advantage of removing the effects of contamination of sample with soil and variability of the moisture content. Knowledge of the chemical composition of the fuel is essential for estimating air requirements and flue losses. It is also of importance in determining likely emissions of pollutants such as nitrogen oxides. The ultimate analysis is often determined according to the standards developed for coal (BS 1016: Part 6, 1977; ASTMD3176-84, 1984).

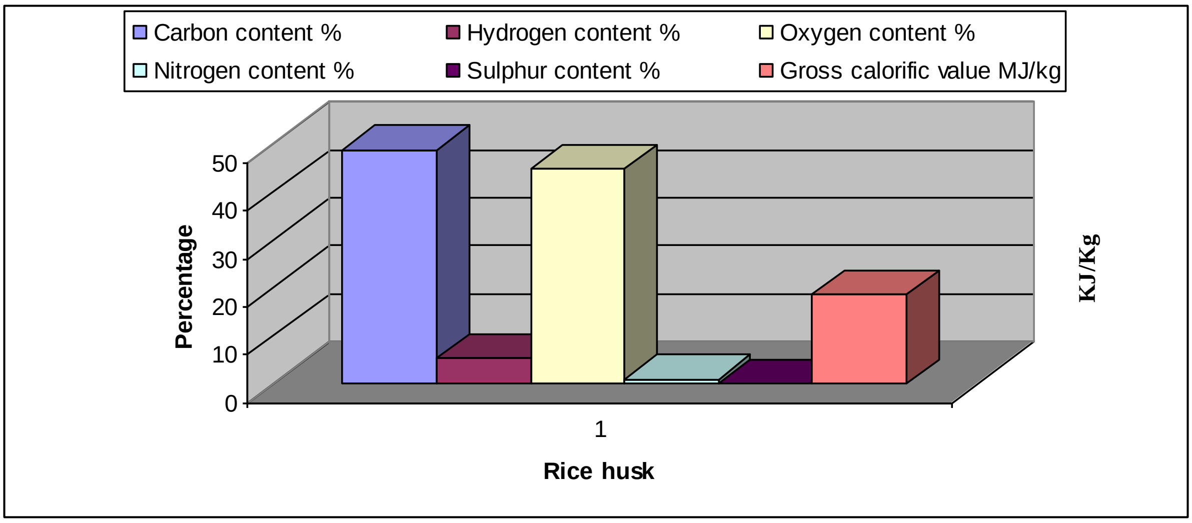


Fig.4.2: Ultimate analysis of rice husk

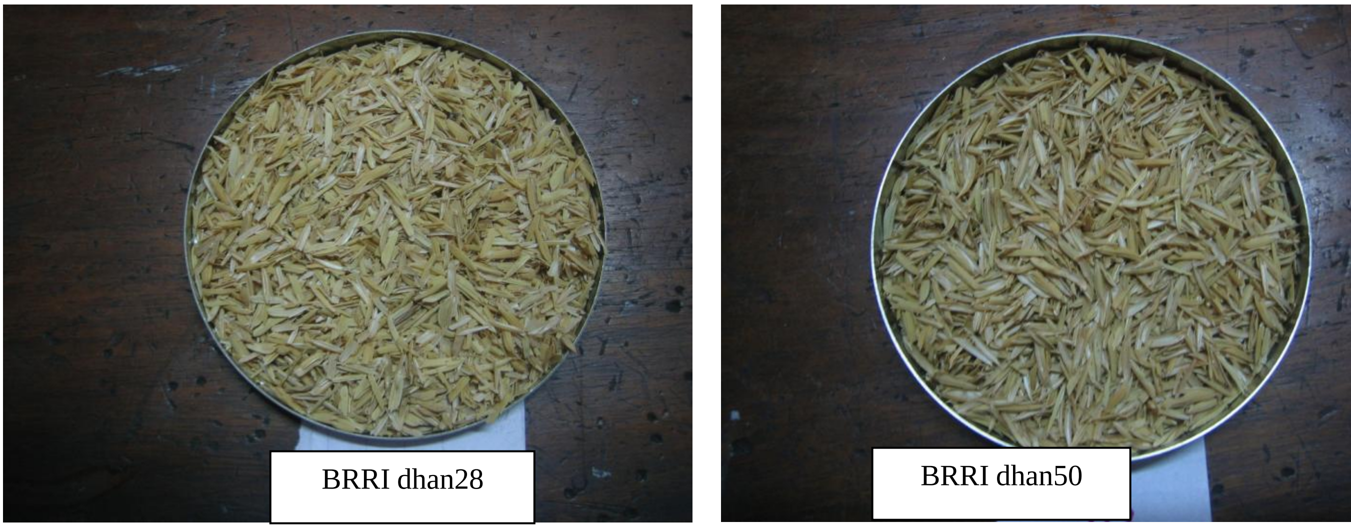


Fig.4.3: Picture of rice husk of Brri dhan28 and BRRI dhan50

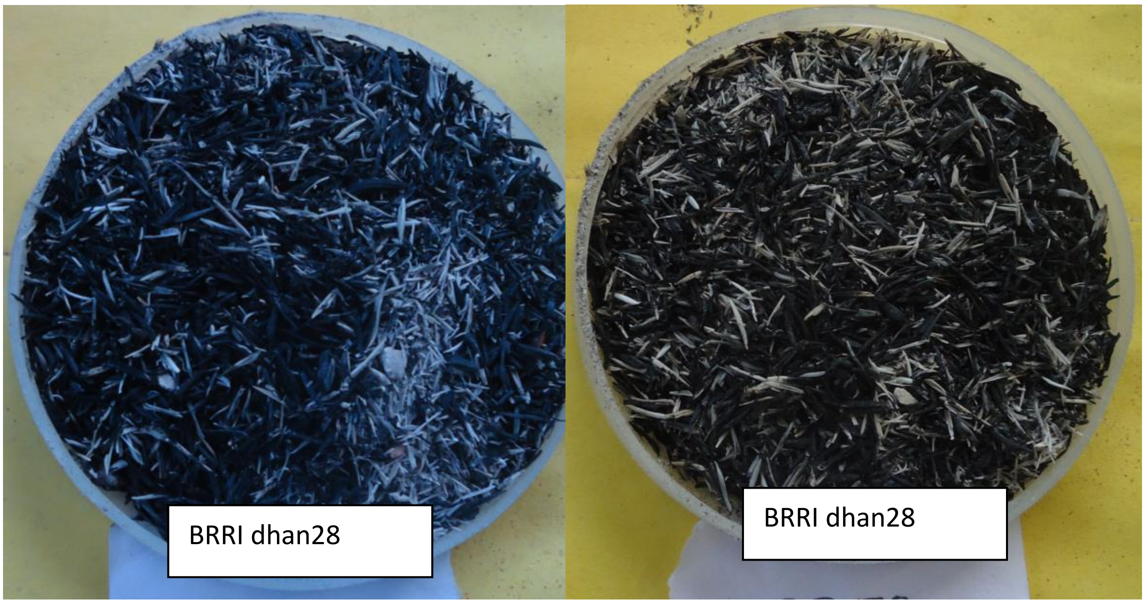


Fig.4.4: Ash picture of BRRI dhan28 and BRRI dhan50

Rossi, 1984 reported the ultimate analysis for rice husk as shown in the figure. As ultimate analysis could not be possible because of facility, secondary data is used to determine carbon, hydrogen, oxygen, nitrogen and sulphur as mass percentage of dry and ash free (daf) material.

4.2. Air fuel ratio for gasification

For complete combustion of 6.3 kg of rice husk, the amount of air required, $(m_a)_{st}$ = 37.35 kg

Actual amount of air supplied for gasification of 6.3 kg of rice husk, m_a = 9.84 kg

$$\therefore \text{Equivalance ratio, (ER)} \ \frac{\lambda}{\lambda_{st}} = \frac{m_a}{(m_a)_{st}} = \frac{9.84}{37.35} = \text{K} = 0.27$$

At this ER ratio, the CO percentage was found maximum 13%.

4.3. Performance of the gasifier

Fig.4.5: Fabrication of Gasifier in the workshop

Fig.4.6: Reactor connected with blower

Fig.4.7: Gasifier in operation

[redacted]

Fig.4.8: Modified version of Gasifier

A numbers of performance test were conducted after fabricating the gasifier according to the design consideration. For each operation 6.3 kg of rice husk was used. A 2.5 inch size blower was used to supply fresh air to the gasifier. To attain the desired velocity gate valve was incorporated to the inlet pipe. According to the air fuel ratio, 4.5 m/s velocity was maintained throughout the process. Each 10 minutes ash was removed from the ash collector. For one batch of operation it took 60 minutes for combustion. The combustible gases which come out from the gasifier pass through three consecutive filters to remove tar and moisture. It was observed that the composition of producer gas was not same at leaving point of the gasifier and at the end point after filtering the gas. This may be due to further thermal or chemical or both reactions happened when the gas flows through the pipe and filters. The flame was detected by firing the gas at the outlet and at the end point after filters fig. 4.1.1 and 4.1.2 Therefore further modification was made with the gasifier. Firstly gas outlet pipe was fitted at the top of the gasifier. The problem encountered with that was the temperature of the producer gas was recorded 80^0 to 90^0 C which is much lower than the required. In this position, tar content and also moisture in the gas was much higher. The expected temperature of the gas is around 200^0 C. To solve this problem the outlet pipe was fitted 7 inches lower from the top of the gasifier. Another outlet pipe was fitted 13 inches lower from the top of the gasifier. Both upper and lower pipe was used to observe the gas properties. One pipe was closed when another one was opened to come out of gas from the gasifier. The percentage of CO in the producer gas that comes out from the upper outlet pipe was better than the lower one. The stove was coupled very close to the gasifier. The stove was coupled 6 inches from the gasifier. Evaluating the two design, the average value of gas composition at 4.5 m/s air velocity is shown in table.

Considering the first design the percentage of gas compositions are shown in the figure:

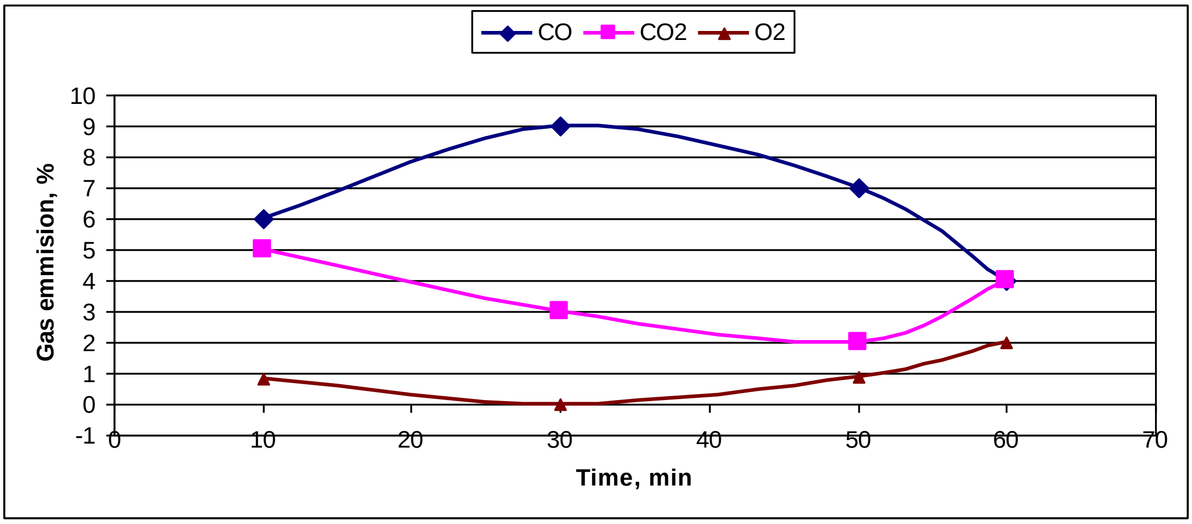


Fig.4.9: Percentage of gas composition obtained from the first version.

This result obtained from considering the first design. This figure represents the percentage of CO, CO_2 and O_2 present in the producer gas. 10 minutes after starting the gasifier, CO_2 and O_2 percentage is little bit higher and is 5% and 0.8% respectively. The CO_2 percentage decrease gradually with time and lowest 2% shows at the time of 50 minute. Hereafter it begins to increase. At 30 minute, the O_2 percentage shows nil. Again after 40 minutes it starts to increase the percentage. At 60 minute, O_2 percentage is 2%. The absolute gasification takes place at the time span 25 to 45 minutes. The percentage of combustible gas CO shows higher at the time of 30 minute and lowest 4% at 60 minute. The percentage of CO is much lower indicates, after gasification the composition of gas was not same from leaving point to the end point. There was a thermo chemical change took place during transportation from leaving to burning stove.

Considering the modified version of the gasier the percentage of gas compositions are shown in the figure:

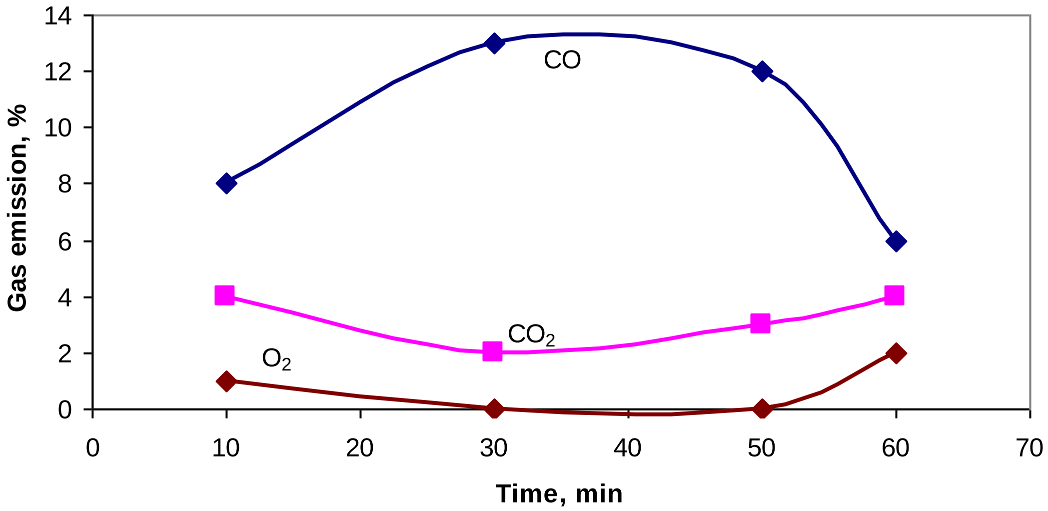


Fig.4.1.0: Percentage of gas composition obtained from modified version.

This result obtained when the second design is considered. Here the producer gas is much more rich with combustible gas CO, which is better than design one. Figure 4.1.0 represents the percentage of gas composition obtained in the whole gasification process. The percentage of O_2 in the producer gas shows 1% at 10 minutes, then from 30 to 50 minutes it shows nil, again after 50 minutes the O_2 in the producer gas is 2%. CO_2 percentage remains slightly higher at the beginning and then sharply falls down with time. In the total 60 minutes time span, the percentage of CO_2 is 4% at the time of 10 minutes after starting the gasifier. Higher percentage of CO_2 at the beginning is as because of the higher quantity of air to be supplied for starting of the gasifier. From 30 to 50 minute the percentage of CO_2 keeps at minimum level of 2% to 3% where the expected gasification takes place. After 50 minutes the percentage of CO_2 again starts to increase is 4%. The main composition in the producer gas is CO. CO is combustible gas. Other combustible gas like H_2 and CH_4 also remain in the producer gas. But, H_2 and CH_4 could not be detected because of unavailability of the instruments. The percentage of CO at 10 minute time is 8%. After 10 minutes the percentage of CO increase sharply and from 30 to 50 minutes time the percentage of CO is highest 12 to 13%. After that CO percentage drastically falls and at the time of 60 minute CO percentage is only 6%. As it is a batch type updraft gasifier, after a certain time the four distinct reaction zones are not remain the same. When the level of the feedstock in the gasifier goes down the thermo chemical reaction get hampered resulting the increase of CO_2 and decrease of CO percentage. Typical Gas composition of producer gas found by Dreams Power Private Ltd. (DPPL), Bangladesh, is: CO-20.62%, H_2-10.62%, CO_2-13.61%, CH_4- Up to 4%, N_2-52.62%. (Source: Infrastructure Development Company Limited (IDCOL), Bangladesh, IDB Bhaban, 6th floor, Agargaon, Dhaka 1207, Phone: 8111235, 8117526, Fax: 8116663, e-mail: idcol@dhaka.agni.com; Website: http://www.idcol.org). Therefore, The CO percentage for updraft gasifier is justified.

The combustible gas CO, H_2 and CH_4 finally burn out in the stove for heating purpose and also detect by firing shown in figure below:

Fig.4.1.1: Combustible gas burning by firing

Fig.4.1.2: Combustible gas burn out in the stove

Fig.4.1.3: Measurement of CO_2 in the producer gas

Fig.4.1.4: Measurement of CO and O_2 in the producer gas

Fig.4.1.5: Measurement of Air velocity in the air inlet pipe

Fig.4.1.6: Measurement of temperature profile of different zone inside the reactor

4.4. Temperature profile of the gasifier

Temperature profile at different zone of the designed updraft gasifier is shown in the figure below:

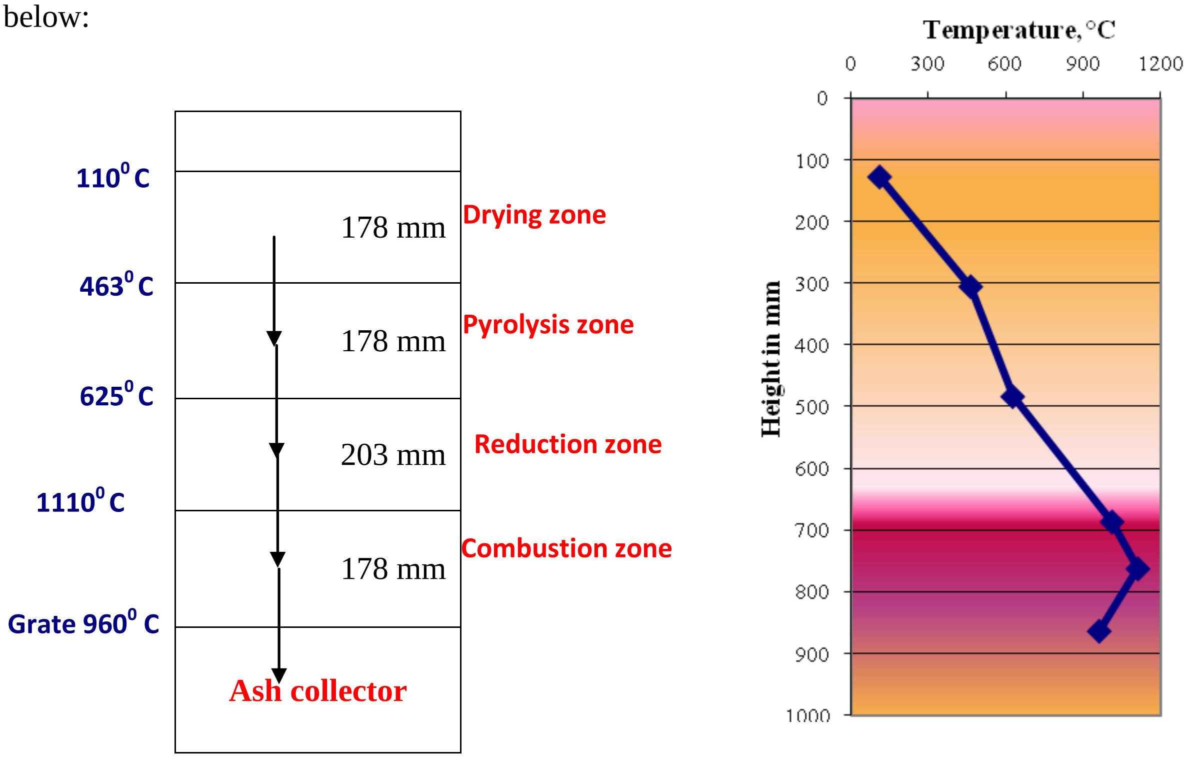


Fig.4.1.7: Temperature at different zone in the gasifier

The above figure represents the average temperature of the different zone in the gasifier. There are four distinct zone in the reactor maintaining different temperature at each layer. The total height of the gasifier is 40 inches in which 6 inch ash pit. The grate is placed at 34 inch distance from the top of the gasifier. Therefore the thickness of rice husk retain in the gasifier is 34 inches which is divided into four zones. The four zones are namely: combustion zone, reduction zone, pyrolysis zone and drying zone. The temperature at the grate was recorded 960^0 C. In combustion zone the average temperature is 1100^0C. The combustion zone is up to 7 inch from the grate. The reduction zone depth is 8 inch and the temperature in this layer is about 625^0 C. Pyrolysis zone is also 7 inch thickness and the average temperature is 463^0 C. The drying zone temperature is 110^0 C and maintaining the average depth of 7 inch. Above the drying zone the average temperature is 90^0 C.

Table 4.3: Approximate estimated cost for fabricating the gasifier

Sl. No.	Materials	Quantity	Price
1	MS sheet 18 gage (244 cm×122 cm)	1 piece	3,000.00
2	MS sheet 22 gage (244 cm×122 cm)	1 piece	2,000.00
3	2 inch pipe	10 ft	700.00
4	1 inch pipe	5 ft	250.00
5	Blower	1 no.	3,500.00
6	Gate valve	1	450.00
7	Union joint	1	350.00
8	Elbow	4	350.00
9	Glass wool	1 piece	1000,00
10	Nut-bolt	0.5 kg	60.00
Total cost			**11,660.00**

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As a result of environmental and policy considerations and depleting of oil resources, there is increasing interest in using renewable energy sources. Biomass gasification is seen as an important technology component for expanding the use of biomass. In Bangladesh, about 54.5% of total land area is used in agriculture. It is estimated that a total 77.40 million tons of biomass produce annually from agricultural sector, among them recoverable amount of rice husk is 10 million tons with 9% moisture content and is of 100 kg/m^3 bulk density can be obtained. Using rice husk as feedstock, an updraft gasifier has been developed and tested. The gasifier is made up with locally available material. The produced gas shows sustainable burning character detected by firing. The CO content in the producer gas has been measured to be 12-13% which is an ideal for a rice husk based updraft gasifier.

5.2 Recommendations for further study

Based on the present study the following recommendations are made for further study

1. Other combustible gas like H_2, CH_4 should be measured.
2. Calorofic value of gas should be quantified.
3. The gasifier should be tested for other agro-waste.
4. The produced gas should be used for running a IC engine.

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APPENDICES

Appendix 1: Feature of Micro manometer (Mark 4 – Testing set)

For standard air at 1.2 kg/m^3 (Corresponding to 16^0C, 1000 mb atmospheric pressure, 55% RH), a velocity pressure of 1 Pascal (1 N/m^2) represents a velocity of 1.291 m/s, and the air velocity at the point of measurement can be calculated according to the following equation:

$$V = 1.291\sqrt{p_v}$$

Where, v = Velocity in meters per second

P_v =Velocity pressure in Pascal (Newton per meter^2)

The pitot static tube**:** Constructed entirely in stainless steel to BS T321 with welded joints, the tube can be safely exposed to temperature up to 953K (680^0C) and for short periods up to 1073K (800^0C). Exceptions to this are the 2.3 mm and 4 mm diameter tubes which have silver brazed joints. These are suitable only for temperature up to 823K (550^0C). Cadmium plated sliding spring clip markers are fitted to the 4mm, 8mm and 9.5mm diameter pitot tubes stems to indicate depth of insertion and can be used at temperatures up to 549K (276^0 C). The pitot tube is connected up to a sensitive manometer to read velocity pressure as indicated in fig.2.2.3. The head of the pitot tube was entered quickly and completely. The duct area in the test plane was measured with care and the volume flow rate was determined by calculating the average velocity in the manner which follows and multiplying it by the measured duct area.

Appendix 2: Feature of Heavy Duty Hot Wire CFM Thermo-Anemometer

The main features of the instrument are as follows:

- Combination hot wire probe (for air velocity) and thermistor sensor (for temperature) deliver rapid and precise measurements even at low air velocity values.
- Slim probe design with telescoping antenna for easy grill and diffuser access.
- Air velocity, air volume and air temperature measurements
- 20 reading average feature
- Zero adjustment
- Data hold and record
- PC interface (RS-232) with optional software and cable for data acquisition

Initialization and zero procedures:

- The meter's probe locking switch must be in th locked position (with the probe inserted) for the meter turn on and then operate correctly
- For best accuracy and for proper operation, the following steps were followed:
- Connected the sensor to the input jack on top of the meter by first unlocking the sensor jack and then inserting the sensor plug. Then locked the sensor jack
- The meter was turned on
- Selected the air velocity function using the function button
- Placed the sensor cover in the up (Zero) position
- Opened the telescoping sensing antenna to a convenient length
- Placed the sensor in the area to be measured and allowed a short time for it to stabilize to the ambient temperature

Appendix 3: Feature of Bacharach Fyrite® Gas Analyzers

The steps were followed to measure CO2 as follows:

- N potassium hydroxide (KOH) was poured into Pyrite kit
- Level the liquid inside kit at zero level
- The metering device was placed at the gas outlet pipe
- The suction pump was pressed 20 times
- Turn around the kit for two or three times
- The percentage of CO_2 shows in the indicator scale

Appendix 4: Feature of DEELTA 65^{-3}GAS-ANALYZER

Small, robust DEELTA 65^{-3}, Gas-Analyzer using electrochemical sensors. Data memory and USB or Bluetooth interface to PC. Battery- and mains operated. The main features of the instrument are as follows:

- Rechargeable battery and mains power supply operation
- Protective rubber case with permanent fixing magnet
- Optimized condensate separator with filter
- Easy-to-read LCD Display
- Infrared interface for printer
- RS 232 Interface
- Internal data memory for up to 100 measurements
- Various probe lengths and materials available

13-20% CO is present in the producer gas. Therefore, dilution of the gas is necessary to measure CO using the Gas-Analyzer as it can measure only 1% (10000 ppm). The following steps were followed to measure CO and O_2 are as follows:

- 50 cc syringe was used to collect producer gas from the outlet pipe
- To dilute the gas by 40 times, 50 cc gas poured into a 2000 cc container
- Sensor probe was entered into the container
- Reading of CO and O_2 on the display was recorded

Appendix-5 Measurement of CO percentage in producer gas considering first design

Time (min)	Diluted reading (ppm)	Dilution factor	Actual CO (%)
10	1520	40	6
30	2260	40	9
50	1755	40	7
60	1010	40	4

Calculation of CO percentage

Dilution factor = 40 (diluted to 40 times than actual)

% CO = $\frac{diluted\ reading}{10{,}00000}\times 100\times dilution\ \ factor\ (d.\ f.)$

Appendix-6 Measurement of CO percentage in producer gas considering modified version

Time (min)	Diluted reading (ppm)	Dilution factor	Actual CO (%)
10	2015	40	8
30	3260	40	13
50	3034	40	12
60	1530	40	6

Calculation of CO percentage

Dilution factor = 40 (diluted to 40 times than actual)

% CO = $\frac{diluted\ reading}{10{,}00000}\times 100\times dilution\ \ factor\ (d.\ f.)$