MAJOR PROJECT - II

OPTIMAZATION OF EQUIVALENCE RATIO FOR DIFFERENT BIOMASS MIXTURE IN THE OPEN TOP DOWN DRAFT GASIFIER.

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF
MASTER OF TECHNOLOGY
IN
THERMAL ENGINEERING

SUBMITTED BY:
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UNDER THE GUIDANCE OF

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DELHI TECHNOLOGICAL UNIVERSITY, DELHI
(2011-2014)

STUDENT DECLARATION

I hereby certify that the work which is being presented in the dissertation, entitled **"OPTIMIZATION OF EQUIVALENCE RATIO FOR DIFFERENT BIOMASS MIXTURE IN THE OPEN TOP DOWN DRAFT GASIFIER"** towards the partial fulfilment of the requirements for the award of the **Degree of Master of Technology** with specialization in Thermal Engineering, from Delhi Technological University Delhi, is an authentic record of my own work carried under the supervision of **Dr. RAJ KUMAR SINGH,** Associate Professor & Co. Guide **Prof R.S. Mishra** Department of Mechanical Engineering at Delhi Technological University, Delhi.

The matter embodied in this dissertation report has not been submitted by me for the award of any other degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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It is certified that **Mr. Anoop Gupta Roll No. 2K11/THE/22,** student of M. Tech Thermal Engineering, Delhi Technological University, has submitted the dissertation titled entitled, **“OPTIMIZATION EQUIVALENCE RATIO FOR DIFFERENT BIOMASS MIXTURE IN THE OPEN TOP DOWN DRAFT GASIFIER”** under my guidance towards the partial fulfillment of the requirements for the award of the degree of Master of Technology.

His work is found to be satisfactory and his discipline impeccable during the course of the project. His enthusiasm, attitude towards the project is appreciated.

We wish him success in all his endeavors.

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ABSTRACT

The aim of this study is to find out the Optimize Equivalence Ratio of biomass mixture with an open top down draft gasifier in order to improve the gasification processes & to make it commercially viable on different type of available biomass not just only woody biomass but also agro residues like rice husk briquette. A single reactor design handles all the bio-residues.

While most gasifier designs are intended to operate with wood chips, the current design is aimed at handling agro-residues that are light, fine sized and with varying ash content. The reactor design replaces the grate by a screw for extracting ash and residual carbon. The problems of handling fine biomass and low melting ash created by the presence of alkalis in the biomass are overcome by briquetting the fine Bioresidue to solid pieces of high density and low moisture content.

An open downdraft gasifier of 35kg/hr was consider to find the effect of equivalent ratio (Actual air fuel ratio to Stoichimetric air fuel ratio: ER) on the specific gas production, the heating value of gas produced and the cold gas efficiency using four combination of biomass viz 100% woody biomass, 100% rice husk briquettes, mixes of 70% wood & 30% rice husk briquettes & 50% wood & 50% rice husk briquettes. Six trials were carried out for each mixture by varying the supply air flow to change the ER. The gas samples were tested for their compositions under steady state operating conditions. Using mass balances for C and N, the cold gas efficiencies, calorific values and the specific gas production rates were determined.

The results showed that with all types of biomass mixes the calorific value of gas reduced with the increase of ER. The cold gas efficiency reduced with ER in a similar trend for all the mixes. The specific gas production increased with ER. Only with 100% rice husk because of its high ash content Low heat value observed & the Equivalence ratio observed is more than 0.5 which showed the process approached towards Combustion instead gasification & the formation of clinker takes place result in poor gas quality because of the high ash fusion temperature of ash. Though if the rice husk blend with other biomass in such a way that the effective bulk density & the corresponding ash content should not exceed more than 750kg/cu.m & 10-12%, then the equivalence ratio close to 0.36 is observed but with the very frequent removal of ash based on the percentage of mixture from the char extraction system.

1. INTRODUCTION

1.1 GENERAL

Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them. Energy can be classified into several types based on the following criteria:

1.Primary and Secondary energy
2.Commercial and Non commercial energy
3.Renewable and Non-Renewable energy

The conventional routes for the generation of base load electric power are Thermal, Nuclear and Hydroelectric. The conventional Thermal Route uses non-renewable energy resources such as Coal, Naphtha, Natural Gas and other Petroleum products which have inherent inflation built into their costs in direct proportion to the rate of foreign exchange, the rate of depletion of the resource and the level of scarcity of the fuel feedstock. This route also adds to the net CO2 load in the atmosphere. Indian coals also suffer from high ash and sulphur contents, which pose a serious effluent disposal problem. This route also suffers from high cost of installation per MW of over Rs. 5.0 Crores, high and rising production cost of unit of electricity, problems of fuel linkage and long gestation of over 3 years.

Nuclear Power Plants need uranium and other rare material resource base as their feedstock. The state of the art Nuclear Power Plants based on fission generate radioactive by-products such as Plutonium, which pose serious disposal problems and are downright inimical to the environment particularly in the vent of an accident as witnessed in the Chernobyl disaster. There is also the threat of theft of these byproducts for production of nuclear missiles. This route also suffers from high cost of installation per MW of Rs. 10 Crores, high and rising production cost of unit of electricity and long gestation periods of over 5 years.

Hydroelectric Plants have become universally unpopular owing to the enormous social and environmental costs involved in their exploitation. Hydroelectric resources are typically located in hilly and inaccessible terrain and the logistics of their installation and regular operation and maintenance are therefore difficult to manage. This route also suffers from long gestation periods of over 6 years and high unit capacity costs. [1]

Other non-conventional sources such as wind energy and solar photovoltaic suffer from high unit capacity costs of Rs. 5.50 Crores and Rs. 20.00 Crores resp. and, therefore, high unit costs of power production. The same problem of unmanageable logistics also afflicts wind energy sites.

The major advantages that Biomass Gasification enjoys over other processes are

1. The principal advantage that Biomass has over other renewable energy resources is its steady and low cost availability throughout the year.
2. Alternatively it can be grown on own land/contracted farmland/wastelands at nominal actual cost, since Prosopsis needs very little water, fertiliser and care.
3. The biomass gasification process provides a sustainable, affordable and eco-friendly alternative to fossil fuel based power plants.
4. It is very cost effective as it combines the low unit capital cost with low unit cost of production.
5. It improves the country’s energy self-reliance and reduces the crippling oil import bill.
6. The entire project is very eco-friendly as it is carbon-dioxide neutral and generates much less of sulphur-dioxide and nitrogen oxides than conventional power plants.
7. Most of the process water is recycled after chemical treatment, thus enhancing the green dot nature of the project.
8. The process produces very low emissions of un-burnt primary fuel and no fly ash, since the solid fuel is subjected to pyrolysis at two stages, with intermediate cleaning and cooling of the gas to remove particulates.
9. The process is very energy efficient as the waste heat in the flue gases is utilized to dry the wet biomass to suit process conditions and for generation of chilling capacity for process needs.

1.1.1 CHARCOAL

The process of gasification of biomass generates about 5% w/w as charcoal via the Ash Extraction Screw. This has fixed carbon of over 70% and Iodine number of 450 – 500.

1.2. BIOMASS GASIFICATION

Biomass has been a major energy source, prior to the discovery of fossil fuels like coal and petroleum. Even though its role is presently diminished in developed countries, it is still widely used in rural communities of the developing countries for their energy needs in terms of cooking and limited industrial use. Biomass, besides using in solid form, can be converted into gaseous form through gasification route.

1.2.1. Concept and Principle

Biomass is a natural substance available, which stores solar energy by the process of photosynthesis in the presence of sunlight. It chiefly contains cellulose, hemicelluloses and lignin, with an average composition of $C_6H_{10}O_5$, with slight variations depending on the nature of the biomass. Theoretically, the ratio of air-to-fuel required for the complete combustion of the biomass, defined as stoichiometric combustion is 6:1 to 6.5:1, with the end products being CO_2 and H_2O. In gasification the combustion is carried at sub-stoichiometric conditions with air-to-fuel ratio being 1.5:1 to 1.8:1. The gas so obtained is called producer gas, which is combustible. This process is made possible in a device called Gasifier, in a limited supply of air.

Gasification is a two-stage reaction consisting of oxidation and reduction processes. These processes occur under sub-stoichiometric conditions of air with biomass. The first part of sub- stoichiometric oxidation leads to the loss of volatiles from biomass and is exothermic; it results in peak temperatures of 1400 to 1500 K and generation of gaseous products like carbon monoxide, hydrogen in some proportions and carbon dioxide and water vapor which in turn are reduced in part to carbon monoxide and hydrogen by the hot bed of charcoal generated during the process of gasification. Reduction reaction is an endothermic reaction to generate combustible products like CO, H_2 and CH_4 as indicated below.

Since char is generated during the gasification process the entire operation is self-sustaining.

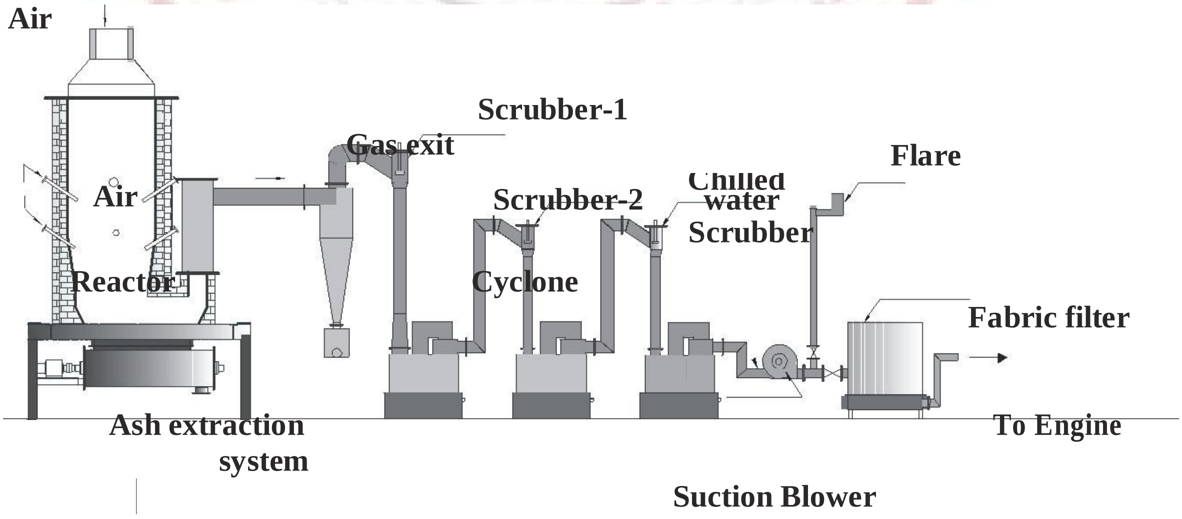


Fig 1.2.1: Typical configuration of the gasifier [1]

1.3 THEORY FORMULATION

1.3.1 Thermo-chemical Reaction COMBUSTION & GASIFICATION [1]

1.3.1.1 Combustion Reaction

$$CH_{1.4}\ O_{0.74}\ N_{0.005} + 0.98\ (O_2 + 79/21 N_2) \longrightarrow CO_2 + 0.7\ H_2O + 3.62\ N_2$$

$$A/F = 5.25$$

1.3.1.2 Gasification Reaction

$$CH_{1.4}\ O_{0.74}\ N_{0.005} + 0.98\ (O_2 + 79/21 N_2) \longrightarrow 0.57\ CO + 0.485\ H_2 + 0.028\ CH_4 + 0.343\ CO_2 + 0.157\ H_2O + 1.27\ N_2 + 0.028\ C$$

$$\longrightarrow 2.857\ (0.2\ CO + 0.17\ H_2 + 0.01\ CH_4 + 0.12\ CO_2 + 0.055\ H_2O +).445\ N_2 + 0.01\ C)$$

$$\longrightarrow 0.157\ H_2O + 0.028\ C + 2.7\ (0.211\ CO + 0.18\ H_2 + 0.0105\ CH_4 + 0.1275\ CO_2 + 0.471\ N_2)$$

1.3.2 Lower Heating Value of Fuel Wood [SERI [10] (1998)]

Bomb calorimeter measures the Higher Heating Value (HHV). The LHV is computed using the following equation.

$\mathrm{LHV} = \mathrm{HHV}\ F_m\mathbf{h}_w$ ………………………………………………………… (4.1)

F_m = Weight fraction of moisture produced in the combustion gas
h_w = Heat of vaporization of water = 2.283MI / kg

$F_m = 0.2226$ (SERI, 1988)

The measurement of fuel consumption and gas flow is difficult, have low accuracy and have higher risk. It is possible to calculate cold gas efficiency without measuring the fuel consumption and gas flow, by means of C and N balance by Modified loss method A-4 (Huisman G.H., 2001), if the analysis of wood and composition of gas are known. This method was used here because measured fuel consumption rate seems to be inaccurate.

1.3.3 Specific gas production – Gas to Fuel Ratio (G/F) [SERI [10] (1998)]

In order to determine the Producer Gas to Fuel Ratio (G/F) carbon balance is used.

Using Carbon balance:

C_f = Cg + Cc-a + Ct…………………………………………...…..... (3.1)
C_f = Rate carbon input to the gasifier with fuel
C_g = Rate carbon leaving the gasifier with producer gas
$C_{c\text{-}a}$ = Rate carbon leaving the gasifier with char-ash
C_z = Rate carbon leaving the gasifier with tar

Assuming carbon in char-ash and tar is negligible compared to carbon in the producer gas;

C_f = C_g ……………………………………………………………… (3.2)

Mass percentage of carbon in dry fuel wood is taken as 52.2% (FAO, 1986)

C_f = 0.552F …………………………………………………………… (3.3)
F = Fuel consumption (Kg / h)

From (3.2) and (3.3);

C_g = 0.522F ………………………………………………………….. (3.4)

Volumetric fraction of carbon in the producer gas is computed as follows:

$$Cgv = \frac{\text{Vol.fraction of C containing component} \bullet \text{Density} \bullet \text{C weight per mole}}{\text{Molecular weight of component}}$$

C_g = Cgv G ……………………………………………………….. (3.5)

G = Producer Gas flow rate (m^3 / h)

From (4.3) and (4.4);

0.522F = C_{gv}G

$$\frac{G}{F} = \frac{0.522}{Cgv} \quad \text{……………………………………………………………………} \quad (3.6)$$

1.3.4 Specific air consumption – Air to Gas Ratio (A/G) [SERI [10] (1998)]

In order to determine the Air flow to Gas flow (A/G) nitrogen balance is used.

Using Nitrogen balance

$N_f + N_a = N_g$

N_f = Rate of nitrogen input to the gasifier with fuel

N_a = Rate of nitrogen input to the gasifier with air

N_g = Rate of nitrogen leaving the gasifier with gas

Assuming nitrogen in fuel is very small compared to the nitrogen in air;

$N_a = N_g$ ……………………………………………………………………… (3.7)

Taking volumetric fraction of nitrogen in air as 0.79;

$N_a = 0.79A$ …………………………………………………………….. (3.8)

Where A = Supply air flow rate

(m^3/h) from (4.7) and (4/8);

$N_g = 0.79A$ …………………………………………………………….. (3.9)

Volumetric fraction of nitrogen in the gas is obtained from the gas composition.

$N_g = N_{gv*}G$ …………………………………………………………... (3.10)

From (4.9) and (4.10);

$0.79A = N_{gv*}G$

$(A/G) = \frac{N_{gv}}{0.79}$ ………………………………………………………….. (3.11)

1.3.5 Equivalent Ratio (ER) [SERI [10] (1998)]

Equivalent Ratio reflects the combined effect of air flow rate and fuel flow rae.
This is defined as the ratio of operating air-fuel ratio to Stoichiometric air-fuel ratio.

$ER = \frac{\text{Operating or Actuals } (\frac{A}{F})}{\text{Stoicheometric } (\frac{A}{F})}$ ……………………………………………… (3.12)

$(A/F) = \frac{\text{Mass of Flow Rate}}{\text{Fuel wood Consumption}} = (A/G)*(G/F)$ = Density of Air …………... (3.13)

Stoichiometric air-fuel ratio is taken as 6.36 kg of air per kg of wood (SEERI, 1988) Based on the equivalence ratio, different types of thermal processes of biomass fuels are characterized as follows.

I) Pyrolysis: $0 \leq \Phi \leq 0.2$

II) Combustion: $\Phi \geq 0.4$

III) Gasification: $0.2 \leq \Phi \leq 0.40$

1.3.6 Lower Heating Value of Gas [SERI [10] (1998)]

Lower Heating value (LHV) of producer gas is determined from the chemical composition of the gas and LHV of individual components.

$(LHV)_{Gas} = \ \Sigma$ volume % of component x *LHV* of the component

1.3.7 Gasification Efficiency

$$n_g = \frac{\text{Heating value of Gas * Gas Flow Rate}}{\text{Heating value of Fuel wood*Fuel Consumption Rate}} \ldots\ldots\ldots\ldots\ldots\ldots \qquad (3.14)$$

1.4 CHEMISTRY [1]

The substance of a solid fuel is usually composed of the elements carbon, hydrogen and oxygen. In the gasifiers considered, the biomass is heated by combustion. Four different processes can be distinguished in gasification: drying, pyrolysis, oxidation and reduction.

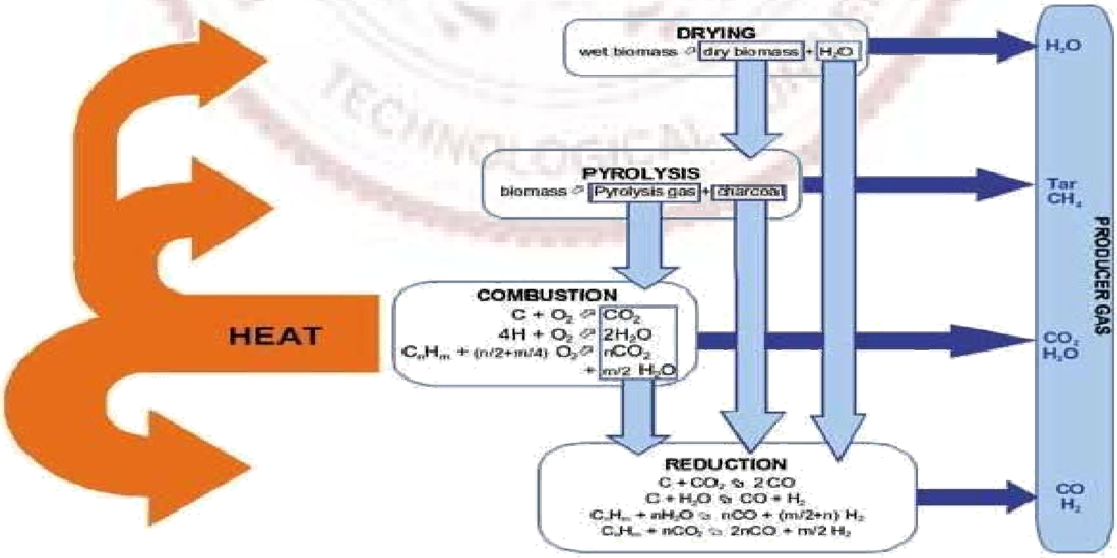


FIGURE: 1.4 Chemistry of Biomass Gasification [1]

The water gas shift reaction determines to a large extent the final gas composition. The equilibrium constant (Kw) can be written as **Kw = [CO2] x [H2] / [CO] x [H2O]** In practice, the equilibrium composition of the gas will only be reached in cases where the reaction rate and the time for reaction are sufficient. Below 700 ° the water-gas shift becomes so slow -without a catalyst- that the equilibrium is said to be 'frozen'. The gas composition then remains unchanged. Methane equilibrium will only be reached at very high temperatures (> 1200°C).

1.4.1 Direct Gasification:

In direct gasification, Oxygen or Air is used as blast. Gasification can be accomplished by using the principal of partial oxidation. In this case exothermic gasification occurs by supplying sub-stoichiometric blast to the process. The equivalence ratio s the amount of oxidant supplied relative to the stoichiometric requirement. Optimum gasification efficiency occurs near an equivalence ratio of 0.26 in purely direct biomass gasification. In practical reality, incomplete conversion will occur due to kinetic limitations of volatile matter conversion and heat and mass transfer limitations of fixed carbon conversion. These affects relate to reactor design constraints and system configuration effects. The amount of tar in the generated gas often depends on reactor design. Minimizing tar with creative equipment design is a principal goal for gasification engineers.

1.4.2 Indirect Gasification:

Indirect gasification is accomplished using steam as an oxidant. However, steam reforming of biomass is endothermic and often heat transfer limited. Endothermic gasification generates more methane than direct gasification per volume of gas, so the energy density may be higher.

The thermal input required for steam reforming of biomass means that some clever method of high rate heat transfer must be devised. Steam gasification is thermodynamically more efficient than direct gasification, but practical heat transfer limitations and thermodynamic availability requirements for high temperature heat exchange often makes reality a bit different.

1.5 TYPES OF REACTORS

Based on the design of gasifiers and type of fuels used, there exists different kinds of gasifiers. Portable gasifiers are mostly used for running vehicles. Stationary gasifiers combined with engines are widely used in rural areas of developing countries for many purposes including generation of electricity and running irrigation pumps. Technologies such biomass gasification that allows utilization of biomass fuel is of great importance. Hence for various fuels and output gas applications, different types of gasifiers are used. Some of the commonly used gasifiers are:

1.5.1 Updraft or Counter-current gasifier

It is one of the oldest and most simplified types of gasifier. In an updraft gasifier, the flow of the biomass particles and the gasification agent (i.e. air/oxygen/steam) is in opposite directions. The air intake is at the bottom and the gas leaves at the top. The combustion reactions occur at the grate that is near the bottom of the gasifier, which are followed by reduction reactions somewhat higher up in the gasifier. As shown in Figure 3.1; in the upper part of the gasifier, heating and pyrolysis of the feedstock occur as a result of heat transfer by forced convection and radiation from the lower zones. The tars and volatiles produced during this process are carried in the gas stream. Ashes are removed from the bottom of the gasifier.

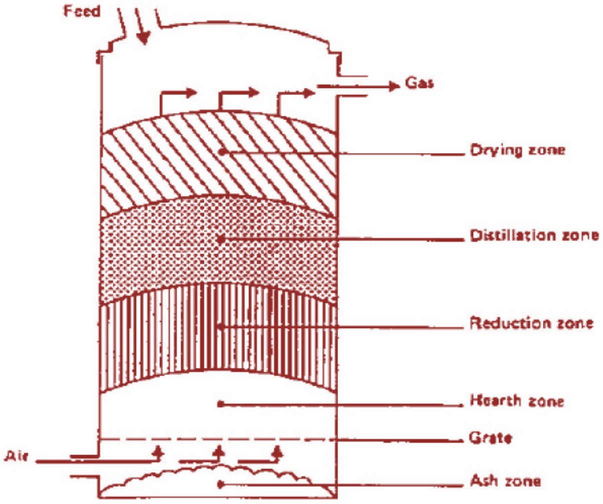


FIGURE: 1.5.1 Updraft Gasifier [1]

The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high equipment efficiency. The drawback of an updraft gasifier is the high amount of tar content that is produced in the gasifier, which makes the producer gas unsuitable for engine applications.

1.5.2 Downdraft or Co-current gasifier

In a downdraft gasifier, the biomass material enters the gasifier through a hopper. In this type of gasifier, there is a co-current flow that gives discrete zones of pyrolysis and char gasification. On their way down the acid and tarry pyrolysis products from the fuel pass through a glowing bed of charcoal and therefore are converted into permanent gas i.e. a mixture of hydrogen, carbon dioxide, carbon monoxide and methane. Depending on the temperature of the hot zone and the residence time of the tar vapors, a near complete breakdown of the tars is achieved.

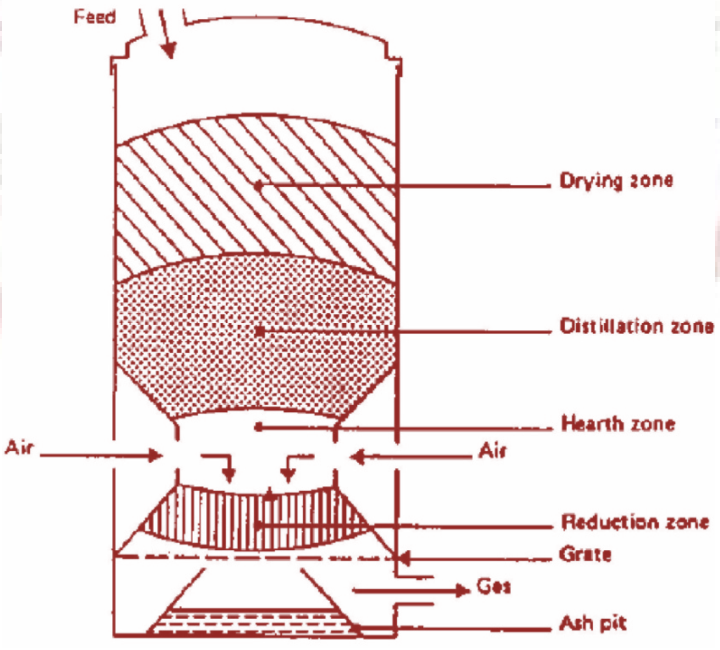


FIGURE: 1.5.2 Down Draft Gasifier [1]

The main advantage of downdraft gasifiers lies in the possibility of producing a tar-free gas suitable for engine applications. However, practically it is highly improbable to achieve a tar-free gas. Also since the levels of organic compounds in condensate are lower for downdraft gasifier and hence it poses less threat to the environment. The major drawback of downdraft equipment lies in its inability to operate on a number of unprocessed fuels. In particular, fluffy and low-density materials give rise to flow problems and excessive pressure drop, and the solid fuel must be pelletized or briquetted before use. Minor drawbacks of the this type of system, as compared to updraft system, are somewhat lower efficiency resulting from the lack of internal heat exchange as well as the lower heating value of the gas.

1.5.3 Cross-draft gasifier

Cross-draft gasifiers are an adaptation for the use of charcoal. Charcoal gasification results in very high temperatures (1500 °C and higher) in the oxidation zone which places constraints on the material used for the structure of the gasifier. In cross draft gasifiers the fuel (charcoal) itself provides insulation against these high temperatures. Advantages of the system lie in the very small scale at which it can be operated. Installations below 10 kW (shaft power) can under certain conditions be economically feasible. The reason is the very simple gas-cleaning train (only a cyclone and a hot filter) which can be employed when using this type of gasifier in conjunction with small engines. A disadvantage of cross-draught gasifiers is their minimal tar-converting capabilities and the consequent need for high quality (low volatile content) charcoal.

1.5.4 Fluidized bed gasifier

The operation, of both up and downdraft gasifiers, is influenced by the morphological, physical and chemical properties of the fuel. Problems commonly encountered are: lack of bunker flow, slagging and extreme pressure drop over the gasifier. As shown in Figure 3.3, air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is originally externally heated and the feedstock is introduced as soon as a sufficiently high temperature is reached. The fuel particles are introduced at the bottom of the reactor, very quickly mixed with almost instantaneously heated up to the bed temperature. As a result of this treatment the fuel is pyrolyzed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar-conversion reactions occur in the gas phase. Most systems are equipped with an internal cyclone in order to minimize char blow-out as much as possible. Ash particles are also carried over the top of the reactor and have to be removed from the gas stream if the gas is used in engine applications.

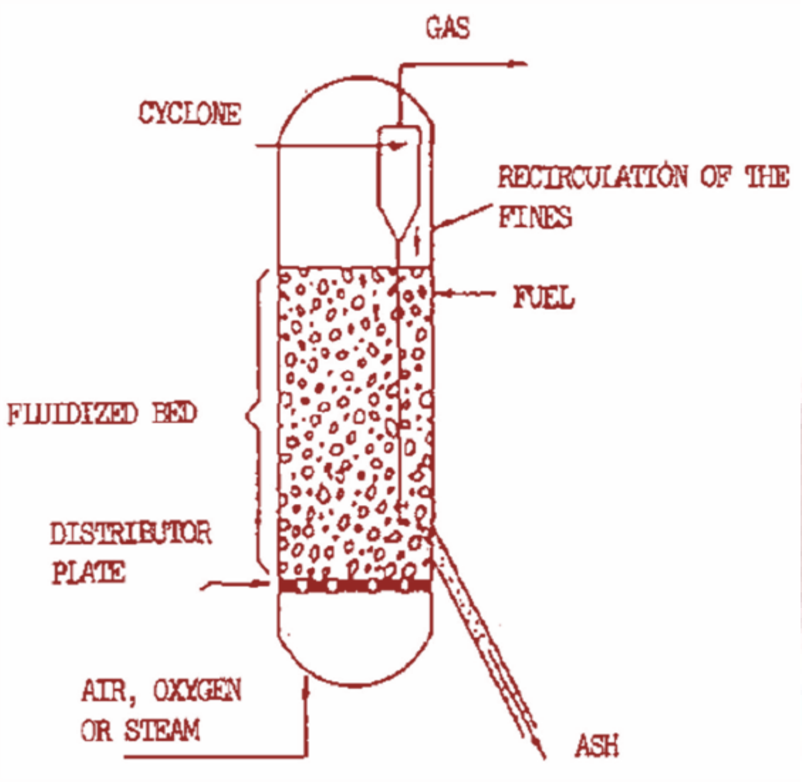


FIGURE: 1.5.4 Fluidized Bed Gasifier [1]

The major advantages of fluidized bed gasifiers come from their feedstock flexibility resulting from easy control of temperature, which can be kept below the melting or fusion point of the ash (rice husks), and their ability to deal with fluffy and fine grained materials (sawdust etc.) without the need of pre-processing. Problems with feeding, instability of the bed and fly-ash sintering in the gas channels can occur with some biomass fuels. Other drawbacks of the fluidized bed gasifier lie in the rather high tar content of the product gas (up to 500 mg/m³ gas), the incomplete carbon burn-out, and poor response to load changes.

1.6 UTILITY OF BIOMASS

Biomass is any natural substance which store solar energy by the process of photosynthesis. It chiefly contains cellulose, hemicelluloses, lignin with an average composition of $C_6H_{12}O_6$ that varies from biomass to biomass.

- ➢ Biomass is any organic matter (plant or animal), which is available on a renewable or recurring basis,
- ➢ Biomass referred here is plant material, either raw or processed, such as: forest, plantation residues, weeds, agricultural residues, wood waste etc
- ➢ Sized forest & plantation residue (woody) could be directly used as the feed stock, however the agricultural residues need to be compacted or briquetted
- ➢ Examples of woody biomass: julifora prosopis, casuriana, Eucalyptus, cotton stalk, mulberry stalks, coconut shells, fronds etc
    - ➢ Density of woody biomass ranges from 200 – 750 kg/m3
- ➢ Examples of agro residues are: sugar cane trash, bagasse, pine needles, rice husk, bamboo dust, coffee husk, peanut husk, sawdust etc.
    - ➢ Density of briquette could be as high as 800 - 1000 kg/m3.
- ➢ The maximum allowable moisture content should be about 12- 15% on dry basis for gasification application

Fig 1.6: Typical Biomass & its briquette [1]

1.6.1 PROPERTIES OF BIOMASS [9]

Following properties of biomass shown in the table.

S No.	Biomass	Proximate analysis		Ultimate analysis				HHV	Density
		wt%		wt% (db)				MJ/Kg	kg/cu.m
		VM	Ash	C	H	N	O		
1	**Bagasse**	84.2	2.9	43.8	5.8	0.4	47.1	16.29	111
2	**Coconut coir**	82.8	0.9	47.6	5.7	0.2	45.6	14.67	151
3	**Coconut shell**	80.2	0.7	50.2	5.7	0	43.4	20.7	661
4	**Coir Pith**	73.3	7.1	44	4.7	0.7	43.4	18.07	94
5	**Corn Cob**	85.4	2.8	47.6	5	0	44.6	15.65	188
6	**Corn stalks**	80.1	6.8	41.9	5.3	0	46	16.54	129
7	**Cotton gin waste**	88	5.4	42.7	6	0.1	49.5	17.48	109
	Ground net shell	83	5.9	48.3	5.7	0.8	39.4	18.65	299
9	**Millet Husk**	80.7	18.1	42.7	6	0.1	33	17.48	201
10	**Rice Husk**	81.6	23.5	38.9	5.1	0.6	32	15.29	617
11	**Rice Straw**	80.2	19.8	36.9	5	0.4	37.9	16.78	259
12	**Subabool wood**	85.6	0.9	48.2	5.9	0	45.1	19.78	259
13	**Wheat Straw**	83.9	11.2	47.5	5.4	0.1	35.8	17.99	222

TABLE 1.6.1: Biomass Ultimate & Proximate Analysis

1.6.2 Characteristics of loose biomass [Ravindran et al]

The loose bio-residues generated from agricultural and industrial activity have fine sizes, generally high ash content and low bulk densities. The bulk density is determined as the mass per unit volume in a container which accounts for void spaces in between the particles.

Biomass	Typical Size	Ash Content	Bulk Density
	mm	%	kg/m3
Rice husk	8- 10	20	100 – 130
Saw Dust	< 3	1 - 3	200 – 250
Coir Pith	< 3	8	80 - 100
Groundnut Shells	8- 20	6	120 – 140
Pine Needle	1 (dia.)	3	80-100

FIGURE: 1.6.2 Typical characteristic of loose biomass [3]

These residues cannot be directly gasified in a packed bed downdraft gasifier for several reasons – (a) the material movement by gravity will be hampered by low bulk density and wall friction, (b) tunnelling of air can occur by the creation of a hole in the bed somewhat randomly affecting the gas quality, (c) operation of the gasifier at high throughputs particularly in a classical closed top design leads to high temperature near air nozzles because of the influence of high velocity air flow from the air nozzles on the char and this can lead to ash softening and clinker formation. The last mentioned feature reduces the effective area for flow through the reactor, further deteriorating the performance of the gasifier; (d) thin walled bio-residues when exposed to high temperature can undergo fast pyrolysis due to high surface area available for reaction. This leads to generation of higher amount of tarry compounds (higher hydrocarbon compounds that can condense and cause deposits in pipe lines and downstream elements) an undesired component for the smooth operation of the system.

1.6.3 Briquetting

The process of briquetting is generally well known; it involves subjecting the biomass to high pressure and temperature which helps in release of lignin from the biomass. This lignin acts as a natural binder and the loose biomass matter gets tightly packed and takes the size and shape of the die. The briquettes ensuing from the briquetting machine will be hot and upon cooling will become hard with individual briquette density varying from 900 to 1100 kg/m^3. This can be preserved for a long time in packed condition. There are two types of briquetting machines, Ram type and screw type. The ram type uses reciprocating mechanism of a punch and a taper die while the screw type uses a rotary mechanism with tapered screw in a heated barrel. The briquette density is found higher in screw type machine than the other one. The bulk densities of loose biomass before and after briquetting are shown in table II, it can be seen that rice husk which is briquetted in screw type machine has a higher briquette density as compared to others done in Ram type machine.

Biomass	Bulk density before briquetting	Briquette density	Bulk density after briquette
	kg/m3	kg/m3	kg/m3
Rice husk	100 -130	1000 – 1100	400 - 450
Sawdust	200 - 250	900 – 1000	300 - 400
Coir pith	80 -100	900 - 950	350 – 400
Groundnut shell	120-140	800 - 850	300 - 350

Table: 1.6.3.1 Bulk Densities of loose biomass before & after briquetting [3]

1.6.4 Ash fusion

The agro residues are characterized with medium to high ash content as shown in Table 4.4.2. This ash additionally has alkali salts that lower the ash fusion temperature. The in-organic content in biomass is not fixed and can vary from region to region and practices adopted for cultivation. A reference data taken from [3] is shown in Table 4.4.2.

Biomass	Ash Deformation Temperature (ºC)	Ash Fusion Temperature (ºC)
Rice husk	1430 – 1500	1650
Coir Pith	1100 – 1150	1150 -1200
Groundnut shells	1180 – 1200	1220 – 1250
Pine needle	1250 – 1300	1350 – 1400

Table: 1.6.4 Ash deformation & Ash fusion temperature of agro residue [3]

The temperature in the oxidation zone can vary between 1200 – 1400 ºC and hence most of the agro residue ash can fuse in this zone. The problem gets aggravated if there are any traces of foreign matter like sand or metal pieces

1.7 PRODUCER GAS

Producer gas is generated in a device known as 'Gasifier', wherein thermo-chemical conversion of biomass occurs in a limited supply of oxidant i.e air. The biomass that could be gasified ranges from forest & plantation residue to agro wastes.

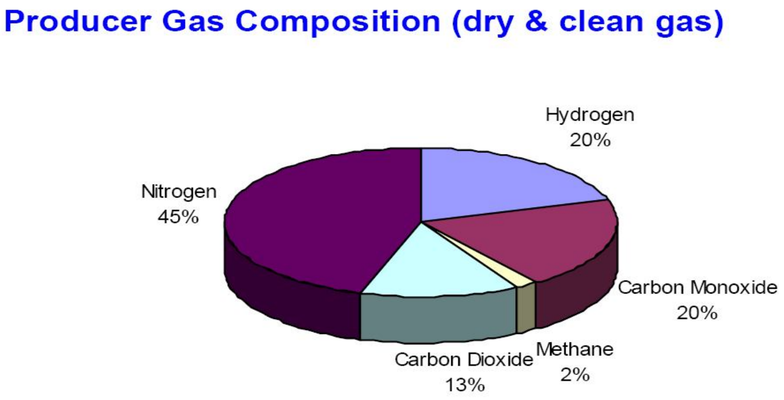


FIGURE: 1.7 PRODUCER GAS COMPOSITION (DRY & CLEAN) [1]

1.7.1 Uses of producer gas

The producer gas obtained by the process of gasification can have end use for thermal application or for mechanical/electrical power generation. Like any other gaseous fuel, producer gas has the control for power when compared to that of solid fuel, in this solid biomass. This also paves way for more efficient and cleaner operation. The producer gas can be conveniently used in number of applications as mentioned below.

1.7.1.1 Thermal

a) Dryers: Drying is the most essential process in beverage and spices industry like tea and cardamom. This calls for hot gases in the temperature range of 120 130°C, in the existing designs. Typically the heat energy required is equivalent to 1 kg of biomass for 1 kg made tea. Gasifier is an ideal solution for the above situation, where hot gas after combustion can **be mixed with the** right quantity of secondary air, so as to lower its temperature to the desired level for use in the existing dryers**.**

b) Kilns: Baking of tiles, potteries require hot environment in the temperature range of 800-950°C. This is presently being done by combusting large quantities of biomass in an inefficient manner. Gasifier could be suitable for such applications, which provide a better option of regulating the thermal environment. There will also be an added advantage of smokeless and soot less operation, whereby enhancing the product value.

c) Furnaces: In non-ferrous metallurgical and foundry industries high temperatures (~650-1000°C) are required for melting metals and alloys. This is commonly done by using expensive fuel oils or electrical heaters. Gasifiers are well suited for such applications.

d) Boilers: Process industries which require steam or hot water use either biomass or coal as fuel in the boilers. Biomass is used inefficiently with higher pollutants like NO_x and with little control with respect to power regulation. Therefore these devices are appropriate to be retrofitted with Gasifier for efficient energy usage.
Apart from these, energy requirements in poultry farms, cold storage devices (vapour compression refrigerator), rubber industry and so on could be met using biomass Gasifier.

1.7.1.2 Power Generation

Producer gas can either be used in mono or dual-fuel mode in reciprocating engines. In case of mono-fuel mode of operation, the gas is fuelled to a SI engine, whereas in the dual-fuel mode it is operated along with small quantity of liquid fuel (high-speed diesel, furnace oil or bio-diesel) in a compression ignition (CI) engine. The choice of mode of operation is entirely dictated by the economics of operation.

1.8 GASIFICATION PROCESS [1]

1.8.1 Feed Pre-Processing System

The woody biomass from the market is cut to size using multi-blade saw cutters. All the pre-processed raw material is stored in the Raw Material Storage shed. This sub-system consists of the following elements:

1. Multi-blade Saw Cutters of suitable capacity 1 Set
2. Briquetting machine

1.8.2 Feed Drying System

The cut biomass is transported by conveyor to a Waste Heat Drier, where waste heat from the flue gas is diluted with ambient air and used to reduce the moisture content of the biomass to 10%. This sub-system consists of the following elements:

1. Biomass Drier Enclosure and floor grating
2. Dilution blower
3. Insulated ducting

1.8.3 Feed Handling System

This pre-processed and dried biomass is then rotated in a rotary sieve, where it is separated from occluded dirt, sawdust and fibre. The dried and cleaned biomass is then transported with conveyor to the Electrically Hoisted bucket and fed into the inlet hopper at the top of the gasifier. This sub-system consists of the following elements:

1. Bottom discharge bucket
2. Distribution Chute

1.8.4 Gasifier Reactor

This open top down draft Gasifier consists of a vertical tubular reactor with an open top and a conical tapering bottom. The reactor is provided with a number of radially arranged air nozzles, which provide the restricted combustion zone with air. The upper part of the reactor is provided with a top seal with a provision for automatic emergency/scheduled plant shutdown. The lower two thirds of the reactor, where the reactor bed temperature exceeds 600°C, is lined with firebricks and a ceramic material of low thermal conductivity to prevent corrosion by hot CO, CO2 & O2. The hot combustible gases generated in the reactor are drawn from under the reactor through an insulated outlet duct. This sub-system consists of the following elements:

1. 35 kg/hr Gasifier reactor
2. Top cover
3. Top cover lifting arrangement
4. Start-up and shut down piping
5. Air nozzles

1.8.5 Gas Cleaning Sub-System

The hot combustible gases leaving the reactor at a temperature of 550-750°K are led to a multi-clone where most of the particulates are removed by centrifugal action. The soot so collected is transferred to the collection bin using valves.

1. Multi-clone arrangement
2. Soot valves
3. Collection Bin

1.8.6 Gas Cooling Sub-System

The gas is then led into set of two coolers each having swirl sprayer arrangement for cooling the gas by directs impingement. The cooling water, in addition to cooling, also scrubs the gases, thus reducing the particulate load. The wash water is then collected in a Wash Water sump and then pumped to the Water Treatment Plant. After treatment, the Wash Water is passed through a cooling tower via piping to reduce its temperature to ambient, collected in a Main Cooling Water sump after which it is pumped back to the coolers in a closed loop. This cooling reduces the temperature of the gases to near ambient and increases their density facilitating better mass flow for induction by the gas engines. This sub-system consists of the following elements:

1. Coolers provided as part of the Gasification System
2. Wash-water sump (RCC)
3. Wash-Water Circulating pumps
4. Main cooling water sump (RCC)
5. Main cooling water pumps
6. Piping for the above

1.8.7 Gas Filtering System

The gas is then led into a Catalytic Converter using Chilled Water where even minute duct particles and aerosols are removed. The gas is then led into a set of fabric filters where all traces of particulates are removed. This sub-system consists of:

1. Chilled Water Scrubber
2. Circulation pumps
3. Chillers of suitable capacity
4. Fabric Filters
5. Piping for the above

1.8.8 Flare Burner

A branch from the gas line passes through a valve into the Main Gas blower via a control valve into a burner for emergency flaring. A second branch of the gas line is connected to an air-line and then on to the gas-engine generators that are specially designed to operate on producer gas.

1. Main gas Blower
2. Flare Burner
3. Flare burner gas ducting
4. Control Valve

1.8.9 Ash Extraction System

When the feedstock is woody biomass the Gasifier generates about 5% of charcoal at the bottom of the reactor. This is periodically drawn by a Screw Extractor automatically from the bottom of the reactor into a special Activation Chamber for further activation into Activated Carbon. This sub-system consists of:

1. Ash extraction screw
2. Ash valves
3. Ash extraction water seal
4. Trolley

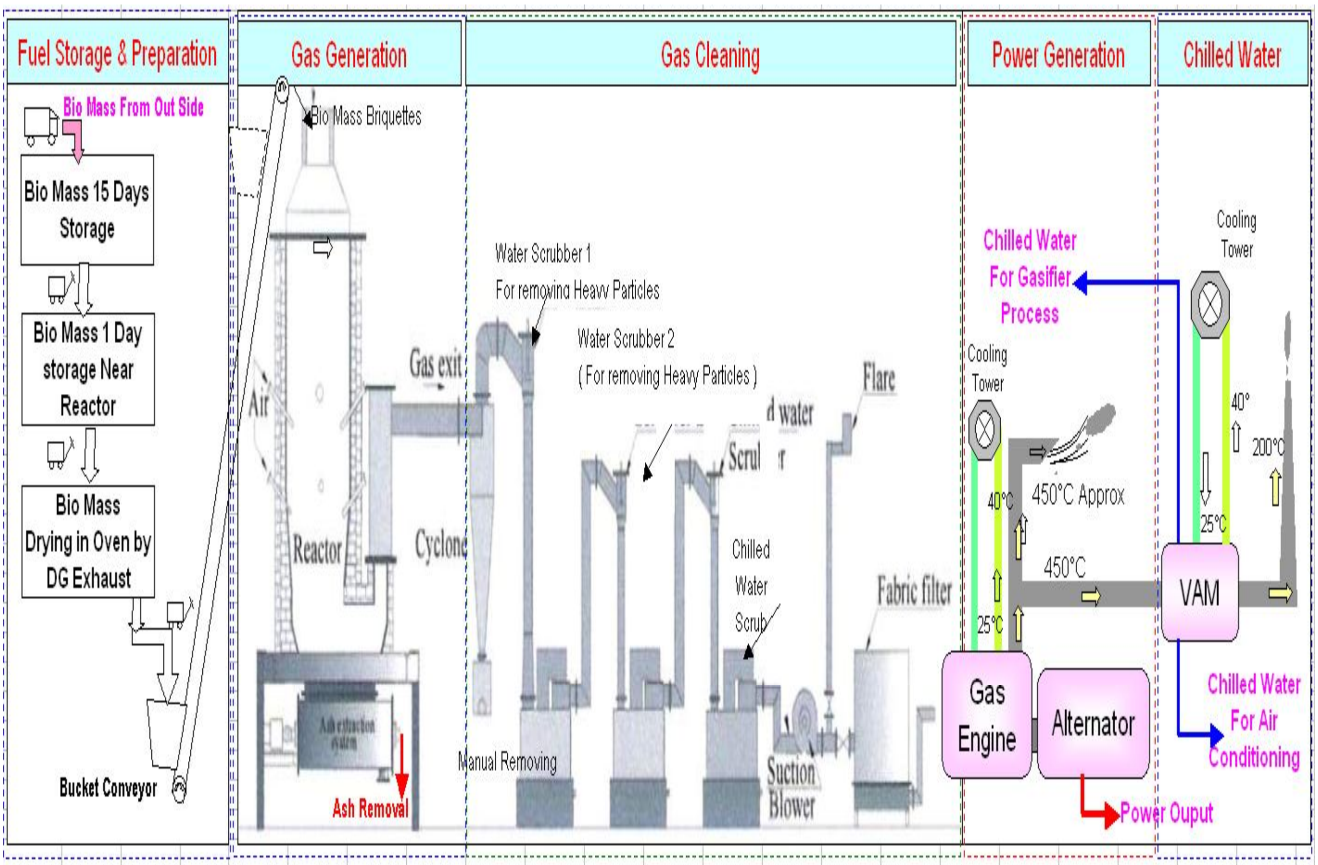
1.8.10 Instrumentation

The on-line instrumentation systems numbering two (one for each stream) provides details of the following operating parameters:

1. Oxygen monitoring sensor to indicate if there is any leakage of air into the system.
2. Water seals to release pressure in case the system gets pressurized and to act as adjunct annunciators of system pressure build-up by producing a bubbling noise.
3. Pressure and temperature sensors for automatic reactor shut down.

1.8.11 Gas Engine Generator

The Power Package consists of 1 Nos. of Gas Engines Model No.XB 5.9 manufactured by of Cummins India Limited and capable of generating 25 kW with producer gas. The gas engines are heat exchanger cooled and the alternators are synchronized with the help of an auto synchronizer on the LT side.



Biomass Briquetts 3000Kg/Hr. CV: 15.8MJ @10% Moisture + Input Air 4500Kg/Hr. Bio Mass Requirement Approx: 54Tons/Day (4Trucks/Day@13.5T/Truck) Approx: 16.5KT/Annum In Plant Storage: 15Days	Bio mass is feed to reactor. Fuel is burned using controlled air at a temp. of 1200C. Air Fuel Ratio 1.5:1 ~ 1.8:1. Producer gas is produced. Two Nos of Gasifiers Capacity : 1500Kg/Hr. Gas Generation: 8100M³/ Hr. H_2:18% , CO:18% , CH_4:1.8% , Co_2: 10.8 % , N_2: 41.4% H_2O: 10% Temp 650°C Particulate: 2800g/Hr.	Cyclone + Cooler + Series of Scrubbers for cleaning Gas. Water recycling: 600m3/Hr Chilled Water Recycling: 300m³/Hr. Outpout Gas 8100M³/ Hr. H_2:20%, CO:20%, CH_4:2%, Co_2: 12 %, N_2: 45.5%, H_2O: 0.5% Temp:15°C Particulate: 2g/Hr.	DG Rating: 987KW Generation Voltage:11KV Nos of DG: 03 Nos Flue Gas Temp: 450°C Flue Gas Flow:6600m3/h DG Make: Woukesha.	Chiller Vacuum Absorption Machine (VAM) Rating : 750TR Process : 150TR Plant A/C : 450TR Make: Thermax.

FIGURE: 1.8.1 Gasification Process

1.9 FACTORS AFFECTING GASIFICATION

Studies have shown that there are several factors influencing the gasification of wood. These include the following [2]:

1.8.1 Energy content of Fuel

Fuel with high energy content provides easier combustion to sustain the endothermic gasification reactions because they can burn at higher temperatures. Beech wood chips have an energy content of approximately 20 MJ/kg. This is typical for most biomass sources and has been proved to be easy to gasify.

1.8.2 Fuel Moisture content

Since moisture is in effect water, a non-burnable component in the biomass, it is important that the water content be kept to a minimum. All water in the feed stock must be vaporized in the drying phase before combustion otherwise there will be difficulty in sustaining combustion because the heat released will be used to evaporate moisture. Wood with low moisture content can therefore than that with high moisture. Wood with high moisture content should be dried first before it can be used as fuel for the gasifier. The beech wood chips used in the experiments have been factory dried to a moisture content of 10% prior to packaging. This makes it suitable as a fuel for the gasifier. Updraft gasifiers are also capable of operating with fuels that have moisture contents of up to 50%.

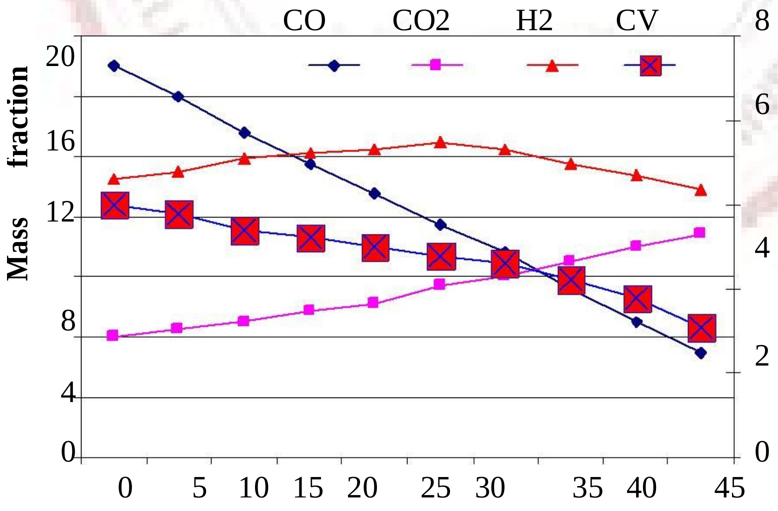


FIGURE: 1.8.2 Moisture content v/s CV [2]

1.8.3 Size Distribution of the Fuel

Fuel should be of a form that will not lead to bridging within the reactor. Bridging occurs when unscreened fuels do not flow freely axially downwards in the gasifier. Therefore particle size is an important parameter in biomass gasification because it determines the bed porosity and thus the fluid-dynamic characteristics of the bed. On the other hand, fine grained fuels lead to substantial pressure drops in fixed bed reactors. The experimental wood chips are approximately 10 x 10 x 2 mm and regular in shape. This size is not fine grained when compared to the micron scale and thus no substantial pressure drops occur in the reactor.

1.8.4 Temperature of the Reactor

There is a need to properly insulate the reactor so that heat losses are reduced. If heat losses are higher than the heat requirement of the endothermic reactions, the gasification reactions will not occur. The reactor in the laboratory has been insulated with 50 mm of alkaline earth silicate to keep heat losses minimal.

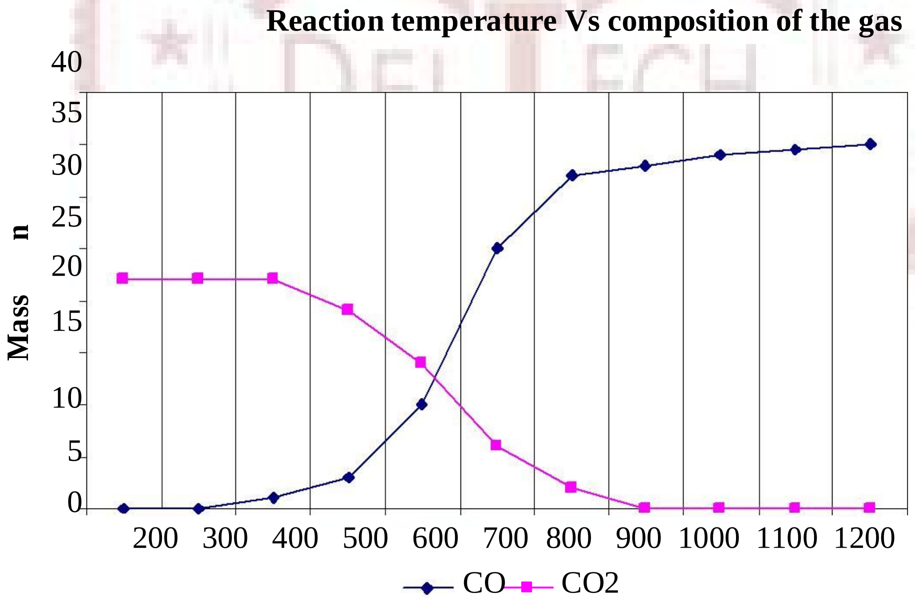


FIGURE: 1.8.4 Temperature v/s Composition of Gas [2]

2. LITERATURE REVIEW

Many studies have done involving to find the optimum equivalence ratio for woody biomass in a down draft gasifier since last three decades. Research organization like TERI, SERI, & IISC have been working vigorously into this field o finding the design of a reactor capable of handling all type of biomass woody & agro residue. IISc has been working extensively in this field & developed an open top down draft gasifier system.
The literature review mainly deals with the study of Equivalence ratio from various blends of agro residue.

Thomas Reed & ray (2005) Developed the concept of equivalence ratio a key to understanding gasification & pyrolysis process & calculated the equilibrium temperature. [11]

Reed et al (2005) Calculated the equilibrium temperatures & compositions for biomass thermal conversion to heat or gas by equivalence ratio to study gasification & pyrolysis. [12]

Gunarathne Duleeka et al. (2009) identified most influential parameters which relates fuel wood gasification using a down draft gasifier to study the effect of equivalence ratio (ER) on the specific gas production, the calorific value of gas produced and the efficiency using three throat diameters (125mm, 150mm and 175mm). F he tested for each throat diameter by via to change the Equivalence ratio, and the gas samples were tested for its composition under steady state running condition using mass balances for each chemical element(C and N), the conversion efficiency, heating value and the specific gas production were determined. The specific gas production increased up to a certain limit with ER under all throat diameters& observed conversion efficiency reduced with ER in a similar pattern for all three throat diameters.& found that the gas composition did not show appreciable change with the change of throat diameter. [13]

Ian Narváez et al (2009) Analyzed equivalence ratio (from 0.20 to 0.45), temperatures of the gasifier bed (750−850 °C) and of its freeboard (500−600 °C), H/C ratio in the feed, use of secondary air (10% of the overall) in the freeboard, and addition (2−5 wt %) of a calcined dolomite mixed with the biomass used as the feedstock with air in a bubbling fluidized bed in a small pilot plant. [14]

Afsin Gungar et al (2009) studied **THE EFFECTS OF THE EQUIVALENCE RATIO ON HYDROGEN PRODUCTION** in fluidized bed biomass gasifiers by increasing the amount of air favours gasification by increasing the temperature but, at the same time, produces more carbon dioxide. Gasification with a better level of efficiency produces more carbon monoxide and less carbon dioxide &is simulated by developed 2D model where the maximum error values do not exceed 0.17. [15]

Andrés et al (2009) It investigated the effect of the air/fuel ratio on gas composition, calorific value and production rate with Other kind of analysis and mass, energy and exergy balances in an updraft fixed bed gasifier were presented by Rao et al. [16]

Huescar Medina et al (2009) studied the effect of torrefied wood biomass & showed a small reduction in reactivity with increasing torrefaction severity and this was attributed to the reduction of volatile content whilst it is thought an increase in the fraction of fines (due to the increase in brittleness) for the more torrefied samples, moderated the effect of volatile content reduction on the reactivity by providing finer particles, easier to burn. The MEC was found to be around 0.2 equivalence ratio (similar to raw biomass), which is less than half that reported for coal. [17]

Salam et al (2010) Reviewed the status of the existing commercial biomass gasification projects in Thailand and Cambodia & identify the types of fuels and technologies used, application of producer gas, technical reliability. [18]

Giovanni Stoppiello et al (2010) correlate the results of reactor design procedures with the physical properties of biomasses and the corresponding working conditions of gasifiers (temperature profile, above all), in order to point out the main differences which prevent the use of the same conversion unit for different materials. [19]

Dos Santos et al (2010) Studied about the flue gas quality obtained from the gasification of several biomass & solid fuels by using Gibbs free energy minimization approach by mathematical algorithm that was implanted in order to simulate the equilibrium composition of CO, CH4, CO2, CH4 by varying equivalence ratio using Brazilian biomass like baggasse, rice husk, oil cale etc at the temperature range between 700°C to 900°C & suggest there is no significant quality change in the gas obtained. [20]

Miguel studied et al (2010) analyzed the effect of the type of gasifying agent used in biomass gasification on product distribution (gas, char and tar yields) and gas quality (contents in H_2, CO, CO_2, CH_4,…, tars) by taking Gasifying agents viz air, pure steam, and steam–O_2 mixtures in biomass gasification in atmospheric and bubbling fluidized bed. [21]

Ruopplo, Miccia et al (2011) investigate and provide further technological and fundamental insights into understanding the effects and drawbacks of using oxygen and steam as gasifying agent during biomass and biomass/coal pellets in fluidized bed. [22]

Bhavnam et al (2011) studied various aspects of research & development in biomass gasification in down draft fixed bed reactors like advances in down draft gasification systems & the effects of various parameters like equivalence ratio, operating temperature moisture content superficial velocity gasifying agents residence time on the composition of producer gas yield. [23]

Bhupendra Gupta et al (2012) discussed various parametric aspects of biomass gasification in terms of zone temperature, calorific value, equivalence ratio, producer gas composition, gas production rate, and cold gas efficiency. [24]

Reed at Etos et al (2012) studied the effect of equivalence ration in biomass stove using wood pellet. [25]

Panda et al (2012) carried out using biomass (rice husk) in a fluidized bed gasifier over a temperature range of 500-700 °C, while varying equivalence ratio from 0.2 to 0.36 and steam to biomass ratio from 0.5 to 1.5 and it was found that the most of trends were similar for both the case. The results showed hydrogen concentration in the product gas increases with increase in temperature and to biomass ratio but decreases with increasing equivalence ratio. [26]

Ashish Malik et al (2012) investigated the simulation of the effects of the equivalence ratio on Hydrogen production in Fluidized bed gasifiers using woody biomass. [27]

Devi, Martin Dio studied et al (2013) Studied the gasifier is optimized to produce a fuel gas with minimum tar concentration. The different approaches of primary treatment are (a) proper selection of operating parameters, (b) use of bed additive/catalyst, and (c) gasifier modifications. The operating parameters such as temperature, gasifying agent, equivalence ratio, residence time, etc. play an important role in formation and decomposition of tar. [28]

Louis et al (2013) studied the concentration of sulphur dioxide & ethylene in the emission of the swirl burner on an equivalence ratio of 2.6 using wood pallets supplied to down draft gasifier system. [29]

Roshan Budhatoki et al (2013) studied 3-D modeling of down draft biomass gasification for equilibrium & finite kinetic approach. [30]

Rajeev Kumar, et al (2014) studied the gasification of juliflora chip is investigated experimentally and the effect of equivalence ratio at 0.23 and temperature on gas composition, gas heating value, gas yield and Gasification efficiency for the temperature range of 700-900°C.Gas composition of experimental data is compared with the theoretical result &found that the concentration of CO2 increases whereas CO decreases with increase in temperature whereas with increasing equivalence ratio the concentration of CO2 increases and the gas heating value decreases. [31]

Ntshengedzeni et al Investigated the efficiency of the gasifier by analysis of the gas profiles at the gasifier using a custom-built gas and temperature measurement system using non-dispersive Infrared gas detection technique is applied to monitor the volume and quality of producer gas, Palladium/Nickel gas sensing is applied to monitor the hydrogen content in the gas stream while the temperature in the gasifier is monitored through the use of K thermocouples & determined the heating value of the producer gas rom the percentage composition of the combustible gases & achieved an efficiency of 75% with an average gas heating value of 6MJ/Nm^3. [32]

Babu et al did the the modeling & Simulation of down draft gasifier by varying equivalence ratio. [33]

Janssen et al studied on the conversion of biomass with air and/or steam into gaseous components and char represented by solid carbon (graphite). Energy and exergy (available energy) losses are analysed by calculating the composition of a dry, ash-free typical biomass feed represented by CH1:4O0:59N0:0017 in equilibrium with varying amounts of air and/or steam. The analysis is carried out for adiabatic systems at atmospheric pressure, with input of biomass and air at ambient conditions and steam at atmospheric pressure and temperature of 500 K. [34]

Aly Mustafa et al studied the effect of the operating parameters such as (temperature, gasifying agent/biomass ratio, pressure) and of the materials, type of biomass) , type of the gasifier reactor on the performance of the gasification. [35]

2.1 RESEARCH GAP IDENTIFIED

The survey of the current literature reveals that no study has been conducted for defining optimum equivalence ratio using biomass mixture of varying ash content in a single gasifier reactor with its effect on gas composition, gasification efficiency, low heat value & gas production rate in an open top down draft gasification system. The present work was completed using mixes of 100% wood, 100% Rice husk briquettes, 30% Rice Husk Briquettes + 70% Woody Biomass, 50% Rice Husk Briquettes + 50 % Woody Biomass.

2.2 OBJECTIVE OF THE PRESENT WORK:

The bulk density of loose agro residue as per Ravindran et al are in the range between 80-200 kg/cu.m which are not desirable to used the fuel in the loose form for Gasification because of the following reason:

(1) Use of incompletely formed briquettes, led to crumpling of the briquettes during the operation and increased the pressure drop across the reactor.

(2) Moisture condensation leads to the formation of poor gas quality.

(3) High ash content in some of the biomass leads to the formation of clinker because of the low ash fusion temperature generating high tar content , low heat value of gas along with the reduced gas flow.

(4) High maintenance cost of ceramic lining.

The aim of the present work identified from the literature survey is to optimize the equivalence ratio in for biomass gasification using single &multi fuel of different densities (solid & loose agro residue converted into briquette) in single & in mixes in an open top down draft gasification by varying the air circulation through nozzles keeping the reactor Dia. & its throat diameter constant for cold gas efficiency & tar content, ash with reactor temperature & to analyse the gas composition by supplying the same into producer gas engine of 35 kwe capacity to measure specific fuel consumption & make it commercially viable.

3.0 EXPERIMENTAL WORK

3.1 EXPERIMENTAL SCHEME

A. A factory assembled gasifier of capacity OPEN TOP DOWN DRAFT GASIFIER OF CAPACITY 35kg/hr complete with cleaning system viz cyclone three stage cooling & cleaning system consists of Direct Cooler, Scrubbers & Chilled Scrubbers and the filtration systems consists of the fabric filter.
B. Multiple air nozzle fitted with control valves to regulate the air supply is established.
C. Producer gas engine of capacity 25 kwe along with the carburettor is fitted to the exit line of filter.
D. Producer gas composition using on line gas analyzers. The gases analysed at different air velocities by closing one or the other valve across air nozzle were analysed were CO, CO2, CH4, O2 & H2. The N2 concentrations were deduced by the difference. The CO, Co2, Ch4 components were determined using infra red gas analyzers & the H2 component using a thermal conductivity based analyzer. The o2 measurement system was based on chemical cell.
E. Reactor temperature through RTD.

3.2 SPECIFICATION OF GASIFIER AT OVN BIO ENERGY.

Biomass consumption (kg/hr)	35
TYPE	OPEN TOP DOWN DRAFT
TURN DOWN RATIO	1:3
AUXILARIES	Cooling Cleaning & Filtration system
REACTOR	
Inner dia (mm)	367.4548
Thickness of Shell (mm)	6
Outer dia (mm)	999
Bun area (m2)	0
Arc height (mm)	250
Total Arch Height	
Outlet gas dia (mm)	155
height above Cone	
outer Dia Of Cone	367
Inner Dia of Cone	294
Cone height	420
Primary nozzle-1	3

Table 3.2 Specification of Biomass Gasifier [1]

3.3 HARDWARE/INSTRUMENTS USED FOR EXPERIMENT

S No.	Description	SPECIFICATION
01	GAS GENSET	100% PRODUCER GAS, CUMMINS MAKE, 25KWE
02	ROTO METER	MAKE : SIEMENS, LEAST COUNT 0.001G/S
03	MANOMETERS	MAKE:JASPIN, RANGE +/-500MM OF WC
04	TEMPERATURE TRANSDUCER	RTD
05	GAS ANALYZER	NDIR, SICK MAHEK
06	OXYGEN MONITOR	MAKE : CHEM LAB, CHEMICAL CELL BASED, 0-21%
07	ANISOLE SOLUTION,THIMBLE FILTER, WASH BOTTLE	Methyl Orange
08	WEIGH BALANCE	0 – 100 Kg Digital type.
09	LOAD BANK	70KWE

Table 3.3 Table of instruments used

3.4 RAW MATERIAL UED FOR TESTING

1. Woody biomass
2. Briquettes of loose agro residue in different proportion with wood

3.4.1 Blending of Different biomass in varying ratio

Blending or Mixing of biomass is done by taking a cubic vessel of dimension 1mX1mX1m in which the bulk density of woody biomass & rice husk briquette was found out by filling the respective biomass to the top in the vessel. The biomass is then weighed in a weighing balance to find out the bulk density. The mixture is then made by filling woody biomass to the level of 0.7 meter & 0.5 meter & balance with the rice husk briquette to find the average bulk density of the mixture. Since from the table by Ravindran et al ultimate & proximate analysis of the biomass known the average value of ultimate & proximate value was determined.

Sno	Fuel	Bulk density in kg/cu.m	Ash content in %	HHV in KJ/Kg	% of Fixed Carbon	Moisture Content in %	Ratio Proportion
1	Wood	450	4	19780	48.2	15	100%
2	Rice Husk	950	20	15290	38.9	12	0%

Table 3.4.1.1 shows the ultimate & proximate analysis of each component in the mixture where only 100% woody biomass used. [1.5.1]

Sno	Fuel	Bulk density in kg/cu.m	Ash content in %	HHV in KJ/Kg	% of Fixed Carbon	Moisture Content in %	Ratio Proportion
1	Wood	450	4	19780	48.2	15	0%
2	Rice Husk	950	20	15290	38.9	12	100%

Table 3.4.1.2 shows the ultimate & proximate analysis of each component in the mixture where only 100% Rice husk briquette used. [1.5.1]

Sno	Fuel	Bulk density in kg/cu.m	Ash content in %	HHV in KJ/Kg	% of Fixed Carbon	Moisture Content in %	Ratio Proportion
1	Wood	450	4	19780	48.2	15	70%
2	Rice Husk	950	20	15290	38.9	12	30%

Table 3.4.1.3 shows the ultimate & proximate analysis of each component in the mixture where 70% woody biomass with 30% Rice husk briquette mixture used. 1.5.1]

	Fuel	Bulk density in kg/cu.m	Ash content in %	HHV in KJ/Kg	% of Fixed Carbon	Moisture Content in %	Ratio Proportion
1	Wood	450	4	19780	48.2	15	50%
2	Rice Husk	950	20	15290	38.9	12	50%

Table 3.4.1.4 shows the ultimate & proximate analysis of each component in the mixture where 50% woody biomass with 50% Rice husk briquette mixture used. [1.5.1]

Sno	Fuel	Average Bulk Density in Kg/cu.m	Average Ash content in %	Avg HHV in KJ/KG	Avg % of Fixed Carbon	Avg % of Moisture	LHV of BIOMASS in KJ/Kg
1	Wood	450	4	19780	48.2	15	19779
2	Rice Husk						

Table 3.4.2.1 shows the ultimate & proximate analysis of the mixture where only 100% woody biomass used.

Sno	Fuel	Avg Bulk Density in Kg/cu.m	Avg Ash content in %	Avg HHV in KJ/KG	Avg % of Fixed Carbon	Avg % of Moisture	LHV of BIOMASS in KJ/Kg
1	Wood	950	20	15290	38.9	12	15289
2	Rice Husk						

Table 3.4.2.2 shows the ultimate & proximate analysis of the mixture where only 100% rice husk briquette.

Sno	Fuel	Avg Bulk Density in Kg/cu.m	Avg Ash content in %	Avg HHV in KJ/KG	Avg % of Fixed Carbon	Avg % of Moisture	LHV of BIOMASS in KJ/Kg
1	Wood	600	8.8	18433	45.41	14.1	18432
2	Rice Husk						

Table 3.4.2.3 shows the ultimate & proximate analysis of the mixture of 70% woody biomass & 30% rice husk briquette.

Sno	Fuel	Avg Bulk Density in Kg/cu.m	Avg Ash content in %	Avg HHV in KJ/KG	Avg % of Fixed Carbon	Avg % of Moisture	LHV of BIOMASS in KJ/Kg
1	Wood	700	12	17535	43.55	13.5	17534
2	Rice Husk						

Table 3.4.2.4 shows the ultimate & proximate analysis of the mixture of 50% woody biomass & 50% rice husk briquette.

3.5 EXPERIMENTAL PROCEDURE

1. Woody biomass of size 1” X 1” with bulk density of about 350-450kg/cu.m along with the briquette of density 950kg/cu.m of rice husk briquette used as an input fuel for different air fuel ratio.
2. Gasifier is a twin air entry system, 70% of the air will be drawn from the top that will be kept constant while 30% of the air will be drawn through the air nozzle fitted at the circumference of the combustion zone around 3 in nos. The air nozzles are called primary air nozzles.
3. For gasification air fuel ratio- 1:1.5 (fuel : air) while stoichimetric condition for biomass combustion -6:1 (air : fuel).
4. The air will be regulated through primary air nozzle fitting valves at the inlet of each nozzle along with the rotometer to measure the mass flow rate of air.
5. The various instrument used for testing were caliberated like oxygen monitor with ambient air conditions, gas analyzers with Nitrogen Gas, Thermocouple & Temperature transmitter with multi-meter using ohmic resistance.
6. The test were planned using different blend of briquetted biomass with wood keeping the ash percentage less than 10 % & by varying density using mixes in different proportion namely at 50% ,100% load for duration of 5 hours.
7. First the Top Cover is lifted & then the water in the air nozzles is emptied.
8. After the Nozzles are emptied, The Flare valve is opened checking the status of Gas valve to be in close position.
9. Then the Direct Cooler Pump starts & circulates the water in a closed loop.

10. After Switching on the Direct Cooler Pump then Chilled Scrubber Pump is switched On for circulating the chilled water at a temperature of 6ºC in a closed loop.
11. The gasifier was ignited at the air nozzles the gas is produced in the flare burner. During this period temperature & pressure drop were measured.
12. Then the Blower is turned on with the Gas valve & closing the flare valve for reaching the producer gas into the gas gen-set at proper pressure for starting of engine.

13. The temperature inside the reactor as well as the gas temperature before feeding the same is measures using k type thermocouples vent is made outside & RTD.
14. The gas was drawn through the system by a vacuum pump & was passed through a anisole solution & thimble filter for tat & dust measurement.
15. Air gas vent is made outside the filter to measure the gas composition using a on line gas analyzer based on NDIR &electrochemical method for Co2 & o2 measurement respectively.
16. Engine is started & put on load.
17. Experiments were conducted using biomass mixture for the measurement of gas composition by varying the air flow at primary nozzle. Air Floe is measured through Roto meter.

Figure 3.5 Testing Rig of Biomass Gasifier

Figure 3.5.1 Briquetting of loose Agro residue

Figure 3.5.2 Processing of Woody Biomass

Figure 3.5.3 Processed Biomass

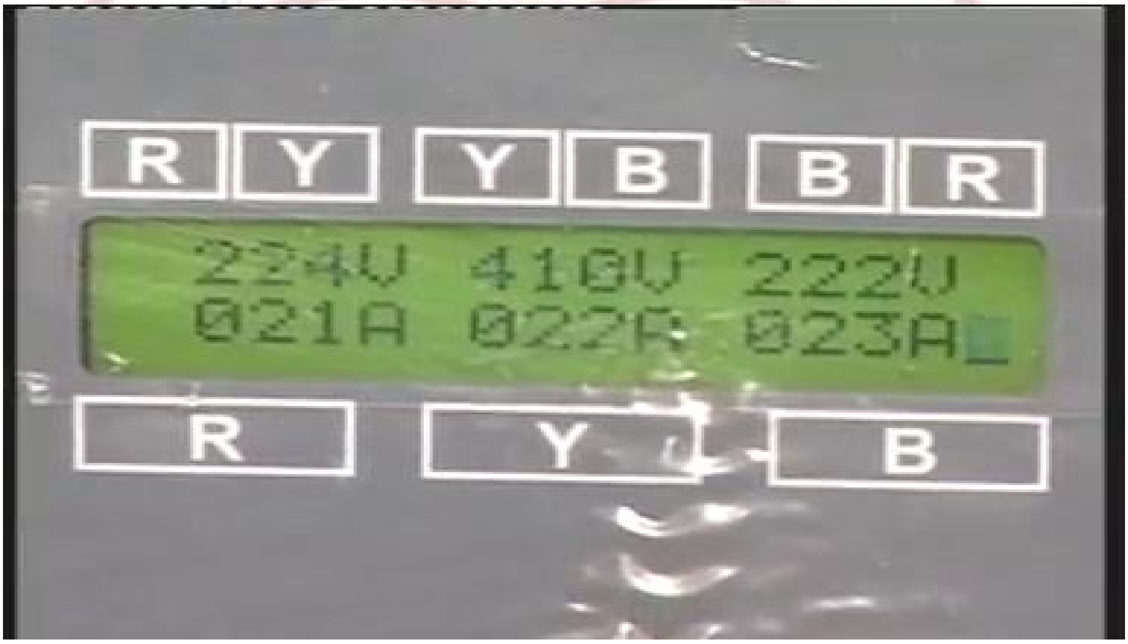
Figure 3.5.4 Rotometer fitted at Air nozzle for measuring air mass flow

Figure 3.5.5 Gasifier Running at Flare mode

Figure 3.5.6 GAS Quality Measurement set up through Gas analyser and oxygen monitor

Figure 3.5.7 Load Readings on Gas Genset

Genset freq Details



Gen-set Load Details

3.6 CALCULATIONS & FORMULAE SERI [10] (1998)

3.6.1 Calculation of Lower Heating Value of Fuel Wood

From equation (4.1)

Lower heating value of fuel wood can be calculated as follows.

$LHV = HHV - F_m h_w$ **-- Equation: 3.1**

$LHV = 19.78 – 0.226\ (2.28\mathbf{3}) = 19.77\ MJ / kg$

For the following calculations, readings of throat diameter; 125mm, air flow setting; 1 was used.

3.6.2 Calculation of Air to Gas Ratio

The volumetric fraction of Nitrogen in the gas,

$N_{gv} = 0.49\mathbf{8}$

From equation (4.10), Air to Gas Ratio,

$$\frac{A}{G} = \frac{N_{gv}}{0.79} = \frac{0.498}{0.79} = 0.63$$ **--Equation: 3.2**

3.6.3 Calculation of Gas to Fuel Ratio

Volumetric fraction of Carbon in the gas can be calculated based on following equation. **--Equation: 3.3**

$$Cgv = \frac{\text{Vol.fraction of C containing component} \bullet \text{Density} \bullet \text{C weight per mole}}{\text{Molecular weight of component}}$$

CH_4 % = 2.1, CO % = 19.48, N_2 %=49.8, H_2%=17, CO_2% = 11.62

Densities: CH_4 – 0.717 kg/m^3, CO-1.25 kg/m^3, CO_2-1.977 kg/m^3

$$C_{gv} = \frac{(0.021)(0.717)(0.012)}{0.016} + \frac{(0.1948)(1.25)(0.012)}{0.028} + \frac{(0.1162)(1..977)(0.012)}{0.044}$$

$$C_{gv} = 0.01129 + 0.1043 + 0.06265 \quad = 0.17824$$

From equation (4.5); Gas o Fuel ratio;

$$\frac{G}{F} = \frac{0.482}{0.17824} = \mathbf{2.70}$$

3.6.4 Calculation of Equivalent Ratio

From equation (4.12), Operating air-fuel ratio;

$$\left(\frac{A}{F}\right)_0 = \frac{A}{F} * \left(\frac{G}{F}\right) * \text{Density of Air} \qquad \textbf{Equation: 3.4}$$

Density of Air = 1.245 * kg/m^2

$$\left(\frac{A}{F}\right)_0 = (0.63)\ (2.70)\ (1.245) = 2.12$$

From equation (4.11), Equivalent Ratio;

$$\text{ER} = \frac{\text{Operating or Actuals } \left(\frac{A}{F}\right)}{\text{Stoicheometric } \left(\frac{A}{F}\right)} = \frac{2.11}{6.36} = 0.334 \qquad \textbf{Equation: 3.5}$$

3.6.5 Calculation of Lower Heating Value of Gas

1.

Component	**Composition (%)**	***Calorific Value (kJ/m^3)**
N_2	49.8	-
H_2	17	10788
CH_4	2.1	35814
CO	19.48	12622
CO_2	11.62	-
Calorific value of producer gas (kJ/m^3)		4646

Table 4.6 Producer Gas Composition & its CV [3]

3.6.6 Lower heating value of gas;

$(LHV)_{\text{Gas}}$ $= \sum$ Volume % of component x LHV of the component **Equation: 4.6**

$(LHV)_{\text{Gas}}$ = (0.499)(0) + (0.17)(10788) + (0.1948)(12622 + (0.021)(35814)+(0.1162)(0)

$(LHV)_{\text{Gas}}$ = 5045 kJ/m^3

3.6.7Calculation of Efficiency of Gasification

Cold gas efficiency;

$$n_g = \frac{\text{Heating value of gas*Gas flow rate}}{\text{Heating Value of Fuel Wood*Fuel consumption rate}} \qquad \text{--Equation: 3.7}$$

This can be rearranged as,

$$n_g = \left(\frac{\text{Heating Value of gas}}{\text{Heating value of Fuelwood}}\right)\left(\frac{\text{Gas Flow Rate}}{\text{Fuel Consumption rate}}\right) \qquad \text{--Equation: 3.8}$$

$$n_g = \frac{5045\ \text{kJm-2} * 2.7\ \text{m2kg-1}}{19779\ \text{kJkg-1}} = \mathbf{68.90\%}$$

4. RESULT & DISCUSSION

4.1 EXPERIMENTAL RESULT:

GAS COMPOSITION The following table shows the variation in the composition of the producer gas for different blends of biomasses at the various air settings through the primary air nozzle in the reactor. It is indicated that the gas composition which consisting Co2 in the range 11-14.5%, CO: 12-19%, H2: 9.5-17% & CH4: 1.2-2.15%.

Air Setting	Air Flow in g/s from Nozzle	Producer gas Composition					
		Biomass	N2 (%)	Co2 (%)	H2 (%)	Co (%)	CH4 (%)
1	0.7	Wood	49.8	11.62	17	19.48	2.1
2	0.65	Wood	51.95	11.89	14.38	19.72	2.06
3	0.67	Wood	51.48	12.12	14.91	19.34	2.15
4	0.67	Wood	51.86	12.87	15.2	18.1	1.97
5	0.68	Wood	52.44	11.83	14.90	19.17	1.66
6	0.63	Wood	55.18	12.19	12.95	18.12	1.56

Table 4.1.1 shows the Variation of Producer Gas Composition with varying air for 100% woody biomass

Air Setting	Air flow in g/s from nozzle	Producer gas Composition					
		Biomass	N2 (%)	Co2 (%)	H2 (%)	Co (%)	CH4 (%)
1	0.73	Rice Husk	65	14	9.5	12	1.7
2	0.78	Rice Husk	61	14.2	10	13	1.8
3	0.82	Rice Husk	58	12.9	10.7	14	1.4
4	0.76	Rice Husk	62.4	14.1	9.7	12.1	1.7
5	0.778	Rice Husk	61.2	14.2	10.2	12.8	1.8
6	0.825	Rice Husk	57.7	12.5	10.7	13.6	1.3

Table 4.1.2 indicates the Variation of Producer Gas Composition with varying air for 100% Rice Husk Briquette

Air Setting	Air flow in g/s from Nozzle	Producer gas Composition					
		Biomass	N2 (%)	Co2 (%)	H2 (%)	Co (%)	CH4 (%)
1	0.70	Rice husk+ Wood	49.51	13.69	15.15	17.01	2.19
2	0.70	Rice husk+ Wood	50.05	12.23	13.69	18.7	2.19
3	0.69	Rice husk+ Wood	50.53	11.96	12.83	18.41	1.96
4	0.68	Rice husk+ Wood	50.31	12.29	13.27	17.34	1.66
5	0.70	Rice husk+ Wood	50.27	11.38	12.61	16.64	1.61
6	0.68	Rice husk+ Wood	51.36	12.33	12.93	14.61	1.55

Table 4.1.3 indicates the variation of Producer Gas Composition with varying air for 70% woody biomass+30% Rice Husk Briquette

Air Setting	Air Flow in g/s from Nozzle	Producer gas Composition					
		Biomass	N2 (%)	Co2 (%)	H2 (%)	Co (%)	CH4 (%)
1	0.84	Rice husk+ Wood	52.36	12.48	11.62	19	2.34
2	0.87	Rice husk+ Wood	50.74	12.81	12.55	15.15	1.41
3	0.88	Rice husk+ Wood	50.31	11.59	12.68	19.57	2.12
4	0.82	Rice husk+ Wood	54.17	11.89	10.53	16.63	1.52
5	0.78	Rice husk+ Wood	56.77	11.59	8.52	17.23	1.71
6	0.80	Rice husk+ Wood	55.28	14.24	9.52	16.22	1.89

Table 4.1.4 indicating the Variation of Producer Gas Composition with varying air for 50% woody biomass+50% Rice Husk Briquette

CALOROPHIC VALUE OF GAS The following tables shows the variation of the Calolrophic value of gas for different blends of biomass when the air fuel ratio varies by regulating the air supply through secondary nozzle of the reactor, the gas composition changes as a result the corresponding calorific value of the generated gas changes. It is observed that for different biomass blends it varies from 1200-1800kg/cu.m.

Air setting	Biomass	Air/gas ratio(A/G)	C_{gv} (CO2)	C_{gv} (CO)	C_{gv}(CH4)	C_{gv} oR F
1	Wood	0.630	0.0627	0.1044	0.0113	0.1783
2	Wood	0.658	0.0775	0.1056	0.0111	0.1943
3	Wood	0.652	0.0804	0.1036	0.0116	0.1956
4	Wood	0.656	0.0820	0.0970	0.0106	0.1895
5	Wood	0.664	0.0803	0.1027	0.0089	0.1920
6	Wood	0.698	0.0698	0.0971	0.0084	0.1753

Table 4.1.5 shows the Variation of Calorific value of producer gas composition per kg of Biomass for 100% Woody Biomass

Air Setting	Biomass	Air/gas ratio (A/G)	Cgv(CO2)	Cgv (CO)	Cgv(CH4)	Cgv or F
1	Rice Husk	0.823	0.0512	0.0643	0.0091	0.1246
2	Rice Husk	0.772	0.0539	0.0696	0.0097	0.1332
3	Rice Husk	0.734	0.0577	0.0750	0.0075	0.1402
4	Rice Husk	0.790	0.0523	0.0648	0.0091	0.1263
5	Rice Husk	0.775	0.0550	0.0686	0.0097	0.1332
6	Rice Husk	0.730	0.0577	0.0729	0.0070	0.1375

Table 4.1.6 shows the Variation of Calorific value of producer gas composition per kg of Biomass for 100% Rice husk Briquette

Air Setting	Biomass	Air/gas ratio (A/G)	Cgv(CO2)	Cgv (CO)	Cgv(CH4)	CGv oR F
1	Rice husk+ Wood	0.627	0.0738	0.0911	0.0118	0.1767
2	Rice husk+ Wood	0.634	0.0659	0.1002	0.0118	0.1779
3	Rice husk+ Wood	0.640	0.0645	0.0986	0.0105	0.1737
4	Rice husk+ Wood	0.637	0.0663	0.0929	0.0089	0.1681
5	Rice husk+ Wood	0.636	0.0614	0.0891	0.0087	0.1592
6	Rice husk+ Wood	0.650	0.0665	0.0783	0.0083	0.1531

Table 4.1.7 shows the Variation of Calorific value of producer gas composition per kg of Biomass for70% woody biomass + 30% Rice husk Briquette

Air Setting	Biomass	Air/gas ratio (A/G)	Cgv(CO2)	Cgv (CO)	Cgv(CH4)	CGv oR F
1	Rice husk+ Wood	0.663	0.0673	0.1018	0.0126	0.1817
2	Rice husk+ Wood	0.642	0.0691	0.0812	0.0076	0.1578
3	Rice husk+ Wood	0.637	0.0625	0.1048	0.0114	0.1787
4	Rice husk+ Wood	0.686	0.0641	0.0891	0.0082	0.1614
5	Rice husk+ Wood	0.719	0.0625	0.0923	0.0092	0.1640
6	Rice husk+ Wood	0.700	0.0768	0.0869	0.0102	0.1738

Table 4.1.8 showing the Variation of Calorific value of producer gas composition per kg of Biomass for50% woody biomass + 50% Rice husk Briquette

Equivalence Ratio, Gasification Efficiency, LHV, SFC of GAS : The following results summarizes that by varying the air flow during testing of different blends of biomass, the gas composition varies which affects the ER, GE, LHV & SFC. It is found that for different blends of biomass, GE varies from 68-79%, LHV from 3300-4500KJ/kg, SFC from 0.9-1.15 kg/Kwe while the ER from 0.33 -0.55.

Air Setting	Biomass	Gas to fuel ratio (G/F)	A/F	Equivalence ratio	LHV gas	Gasification Efficiency in %	SFC
1	Wood	2.70	2.12	0.334	5045	68.9	0.943
2	Wood	2.48	2.03	0.319	4778	59.9	1.084
3	Wood	2.46	2.00	0.314	4820	60.1	1.082
4	Wood	2.54	2.08	0.327	4630	59.5	1.092
5	Wood	2.51	2.08	0.326	4622	58.7	1.108
6	Wood	2.75	2.39	0.376	4243	59.0	1.102

Table 4.1.9 shows the Variation of Parameters VIZ GAS FLOW, EQUIVALENCE RATIO, GASIFICATION EFFICIENCY, LHV & SFC for 100% woody biomass at varying air flow.

Air Setting	Biomass	Gas to fuel ratio (G/F)	A/F	Equivalence ratio	LHV gas	Gasification Efficiency in %	Thermal Efficiency	SFC
1	Rice Husk	4.19	4.29	0.674	3148	86.2	28%	1.0
2	Rice Husk	3.92	3.77	0.592	3364	86.2	28%	1.0
3	Rice Husk	3.72	3.40	0.535	3423	83.3	28%	1
4	Rice Husk	4.13	4.07	0.639	3183	86.1	28%	1.0
5	Rice Husk	3.92	3.78	0.594	3361	86.1	28%	1.0
6	Rice Husk	3.80	3.45	0.543	3336	82.8	28%	1.0

Table 4.1.10 shows the Variation of Parameters VIZ GAS FLOW, EQUIVALENCE RATIO, GASIFICATION EFFICIENCY, LHV & SFC for 100% Rice husk briquette at varying air flow.

Air Setting	Biomass	Gas to fuel ratio (G/F)	A/F	Equivalance ratio	LHV of gas	Gasification Efficiency in %	SFC
1	Rice husk+ Wood	2.95	2.30	0.36	4566	75.3	0.95
2	Rice husk+ Wood	2.93	2.31	0.36	4622	75.7	0.95
3	Rice husk+ Wood	3.01	2.39	0.38	4410	74.0	0.97
4	Rice husk+ Wood	3.11	2.46	0.39	4215	73.1	0.98
5	Rice husk+ Wood	3.28	2.60	0.41	4037	73.9	0.97
6	Rice husk+ Wood	3.41	2.76	0.43	3794	72.2	0.99

Table 4.1.11 Shows the Variation of Parameters VIZ GAS FLOW, EQUIVALENCE RATIO, GASIFICATION EFFICIENCY, LHV & SFC for70% woody biomass + 30% Rice husk briquette at varying air flow.

Air Setting	Biomass	Gas to fuel ratio (G/F)	A/F	Equivalance ratio	LHV of Biomass in KJ/KG	Gasification Efficiency in %	SFC
1	Rice husk + Wood	2.87	2.37	0.373	17019	75.8	0.997
2	Rice husk + Wood	3.31	2.64	0.416	17019	73.3	1.031
3	Rice husk + Wood	2.92	2.32	0.364	17019	78.9	0.958
4	Rice husk + Wood	3.23	2.76	0.434	17019	71.8	1.052
5	Rice husk + Wood	3.18	2.85	0.448	17019	69.3	1.090
6	Rice husk + Wood	3.00	2.62	0.411	17019	66.2	1.141

Table 4.1.12 shows the Variation of Parameters VIZ GAS FLOW, EQUIVALENCE RATIO, GASIFICATION EFFICIENCY, LHV & SFC for 50% woody biomass + 50% Rice husk briquette at varying air flow.

4.2 Evaluation of Performance Parameters

The figure 5.1 is the graph between Equivalence Ratio v/s Low heat value of gas, Gasification Efficiency & Gas flow rate of 100 % woody biomass, indicates that the max gasification efficiency of 69%, max low heat value of gas of 5054Kj/kg, lowest specific fuel consumption 1.01 kg/kwh with as production of about 2.72m3/kg is obtained at the equivalence ratio of 0.334 which is the optimum point after which as the equivalence ration increases, gasification efficiency, low heat value of gas decreases .

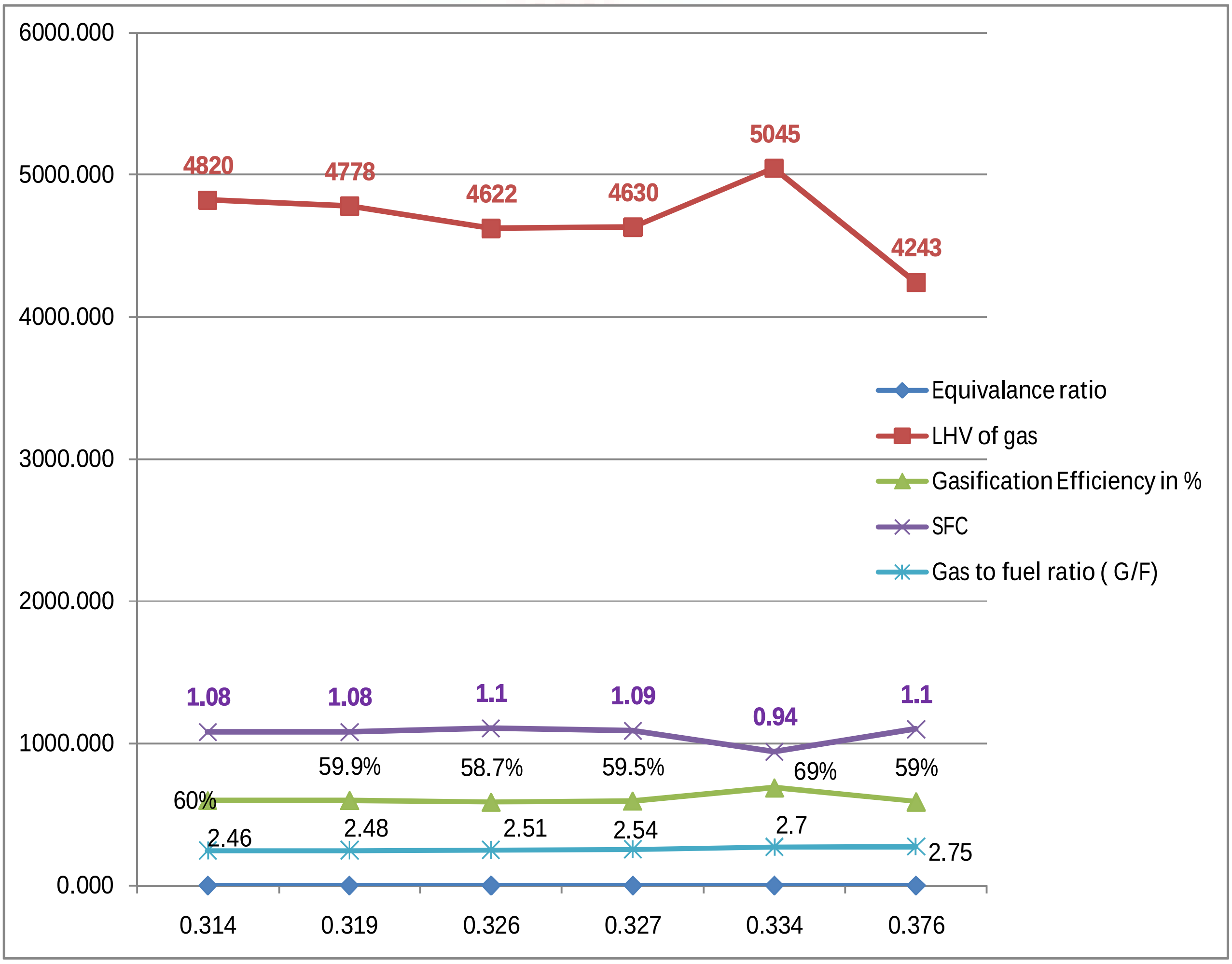


Fig 4.1 Performance of GE, LHV, SFC, G/F against varying ER for 100% woody Biomass.

The figure 5.2 is the graph between Equivalence Ratio v/s Low heat value of gas, Gasification Efficiency & Gas flow rate of 70 % woody biomass + 30% rice husk briquette, indicates that the max gasification efficiency of 75.7%, max low heat value of gas of 4622KJ/kg, lowest specific fuel consumption 0.95 kg/kwh with as production of about 2.93m3/kg is obtained at the equivalence ratio of 0.334 which is the optimum point after which as the equivalence ration increases, gasification efficiency, low heat value of gas decreases.

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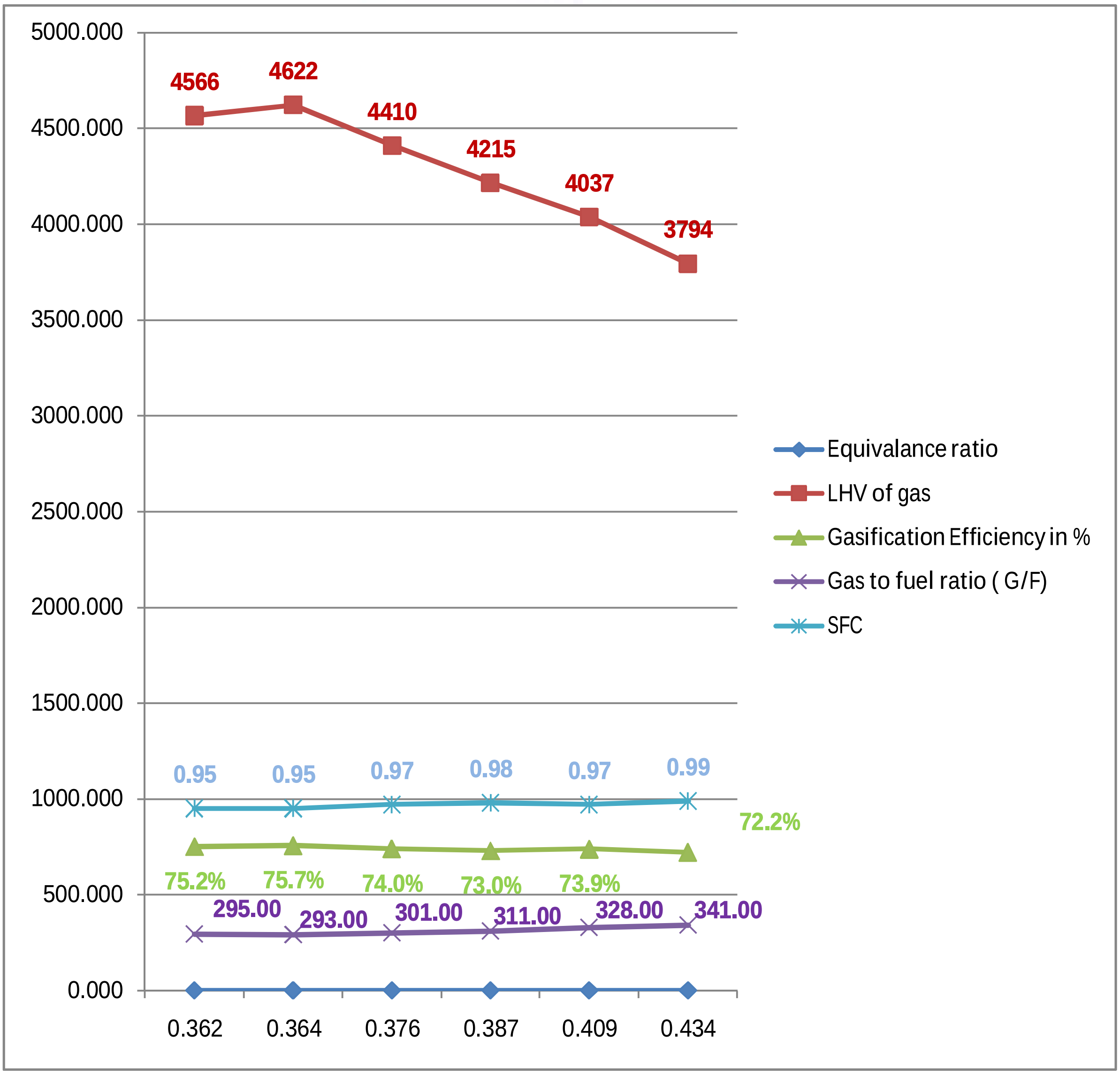

Fig 4.2 Shows the Performance of GE,LHV,SFC,G/F against varying ER for 70% woody Biomass+30% Rice husk briquette.

The figure 5.3 is the graph between Equivalence Ratio v/s Low heat value of gas, Gasification Efficiency & Gas flow rate of 50 % woody biomass +50% rice husk briquette, indicates that the max gasification efficiency of 78.9%, max low heat value of gas of 4597KJ/kg, lowest specific fuel consumption 0.96 kg/kwh with as production of about 2.92m3/kg is obtained at the equivalence ratio of 0.334 which is the optimum point after which as the equivalence ratio increases gasification efficiency low heat value of gas decreases.

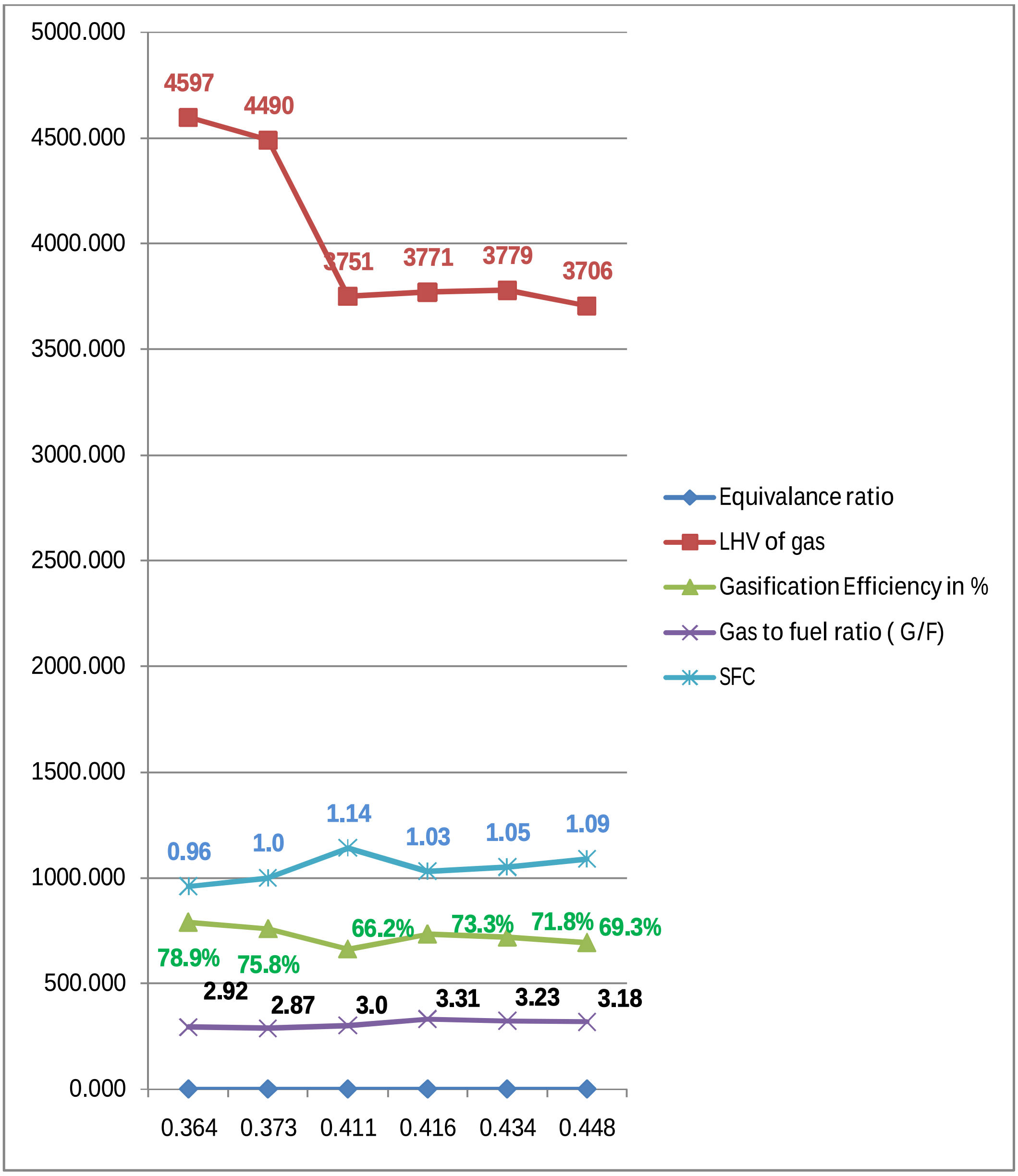

Fig 4.3 Shows the Performance of GE,LHV,SFC,G/F against varying ER for 50% woody Biomass+50% Rice husk briquette.

Figure 5.4 is the graph between Equivalence Ratio v/s Low heat value of gas, Gasification Efficiency & Gas flow rate of 100% Rice husk briquettes blend, indicates that the max gasification efficiency, max low heat value of gas, lowest specific fuel consumption is obtained at the equivalence ratio of 0.59 which is the optimum point after which as the equivalence ration increases, gasification efficiency, low heat value of gas decreases. The high gas production rate is because of high equivalence ratio. The reaction is shifting towards combustion to gasification.

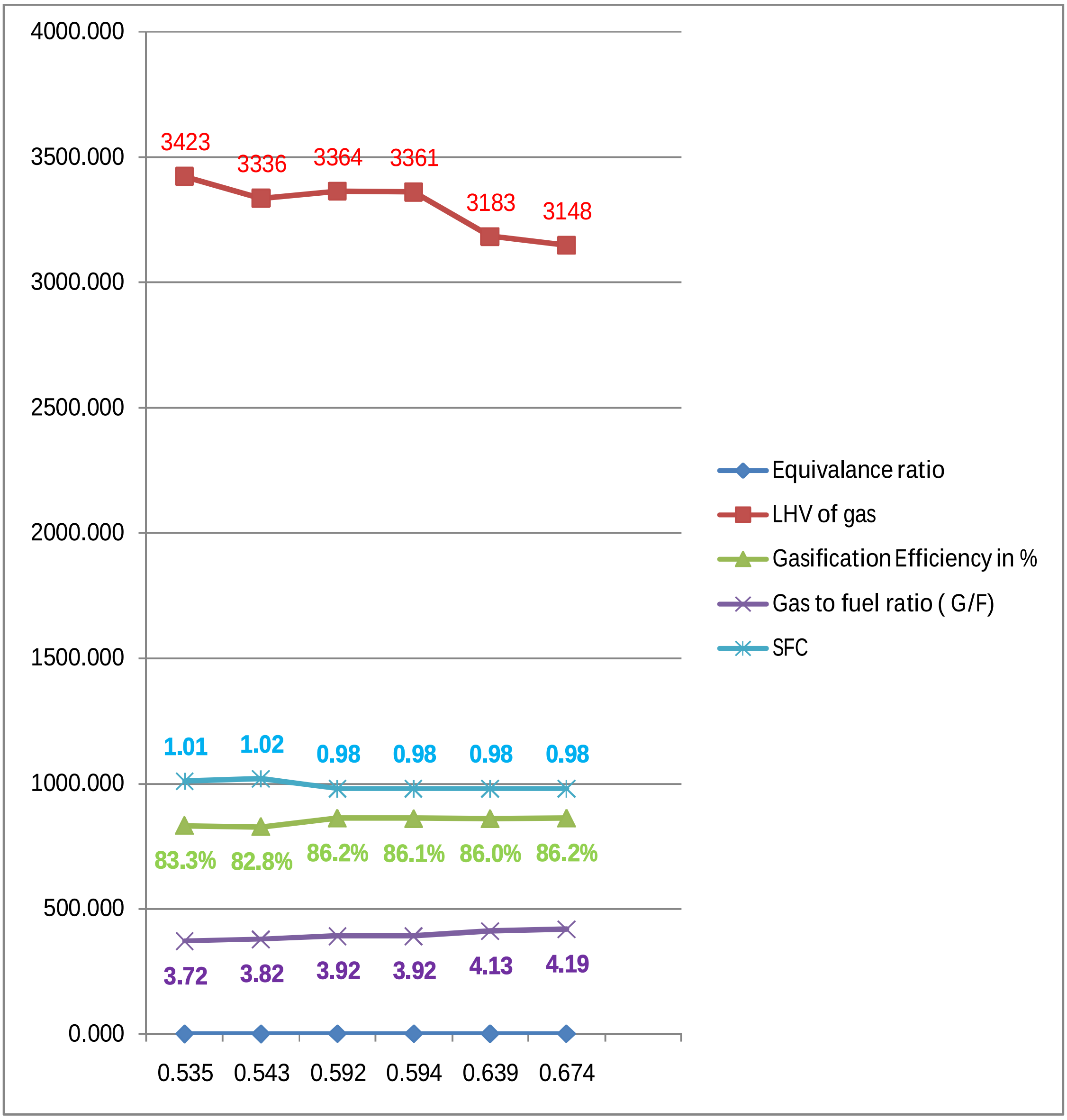

Fig 4.4 Shows the Performance of GE,LHV,SFC,G/F against varying ER for +50% Rice husk briquette.

4.3 VARIATION OF GAS COMPOSITION WITH EQUIVALENCE RATIO

The fig 5.5 shows the variation in composition of producer gas with Equivalence ratio for 100% woody biomass & it observed that the percentage of CO2 -11.62%,Co-19.72%,H2-17% ,CH4-2.1% & rest N2 at the optimum Equivalence ratio of 0.334.

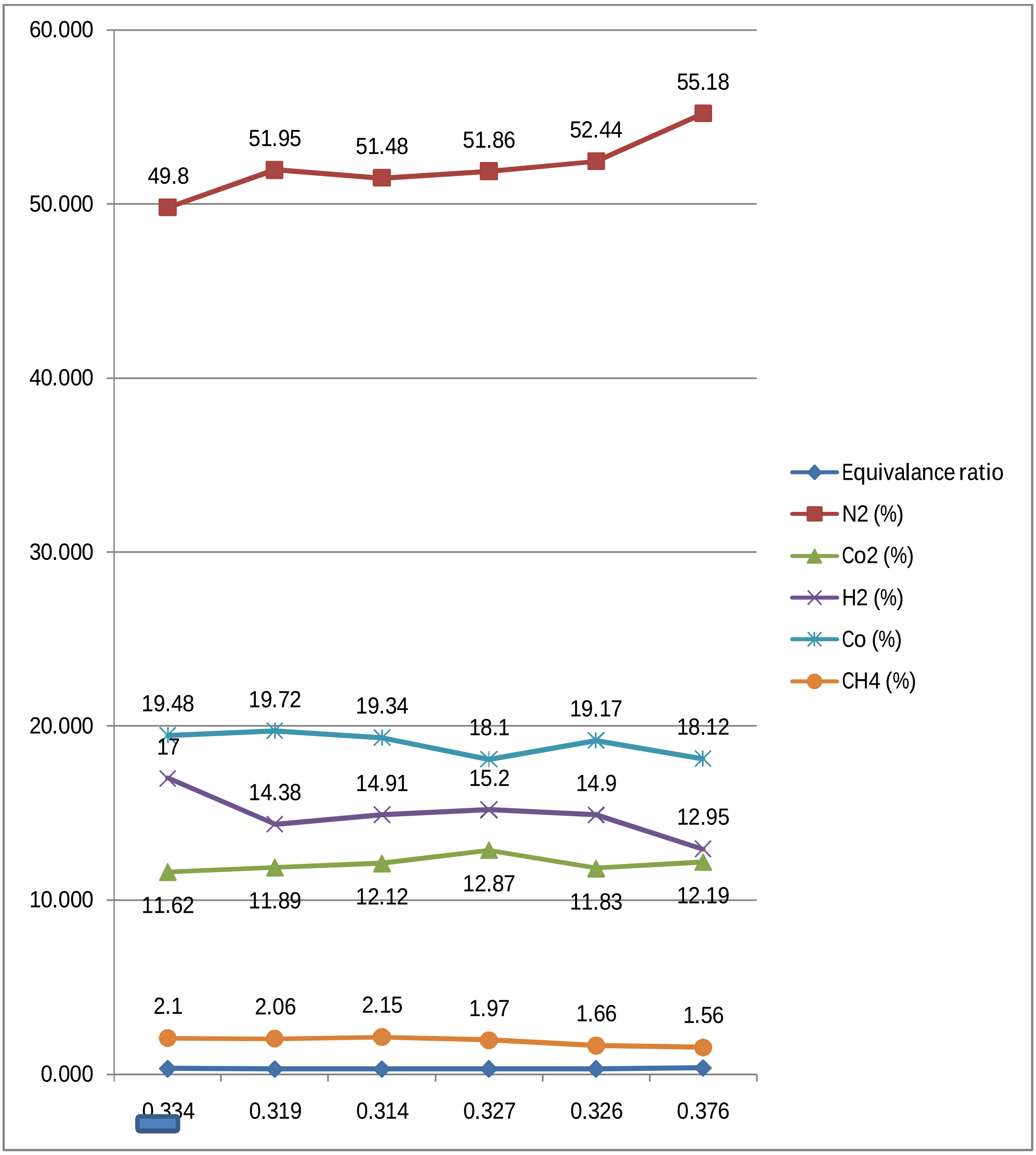

Fig 4.3.1 Shows the variation of GE,LHV,SFC,G/F against varying ER for 100% woody biomass.

The fig 5.2.2 shows the variation in composition of producer gas with Equivalence ratio for 100% Rice Husk Briquette & it observed that the percentage of CO2 -12.90%,Co-14%,H2-10.2% ,CH4-1.4% & rest N2 at the optimum Equivalence ratio of 0.535.The composition shows the reactor is behaving badly in terms for gasification.

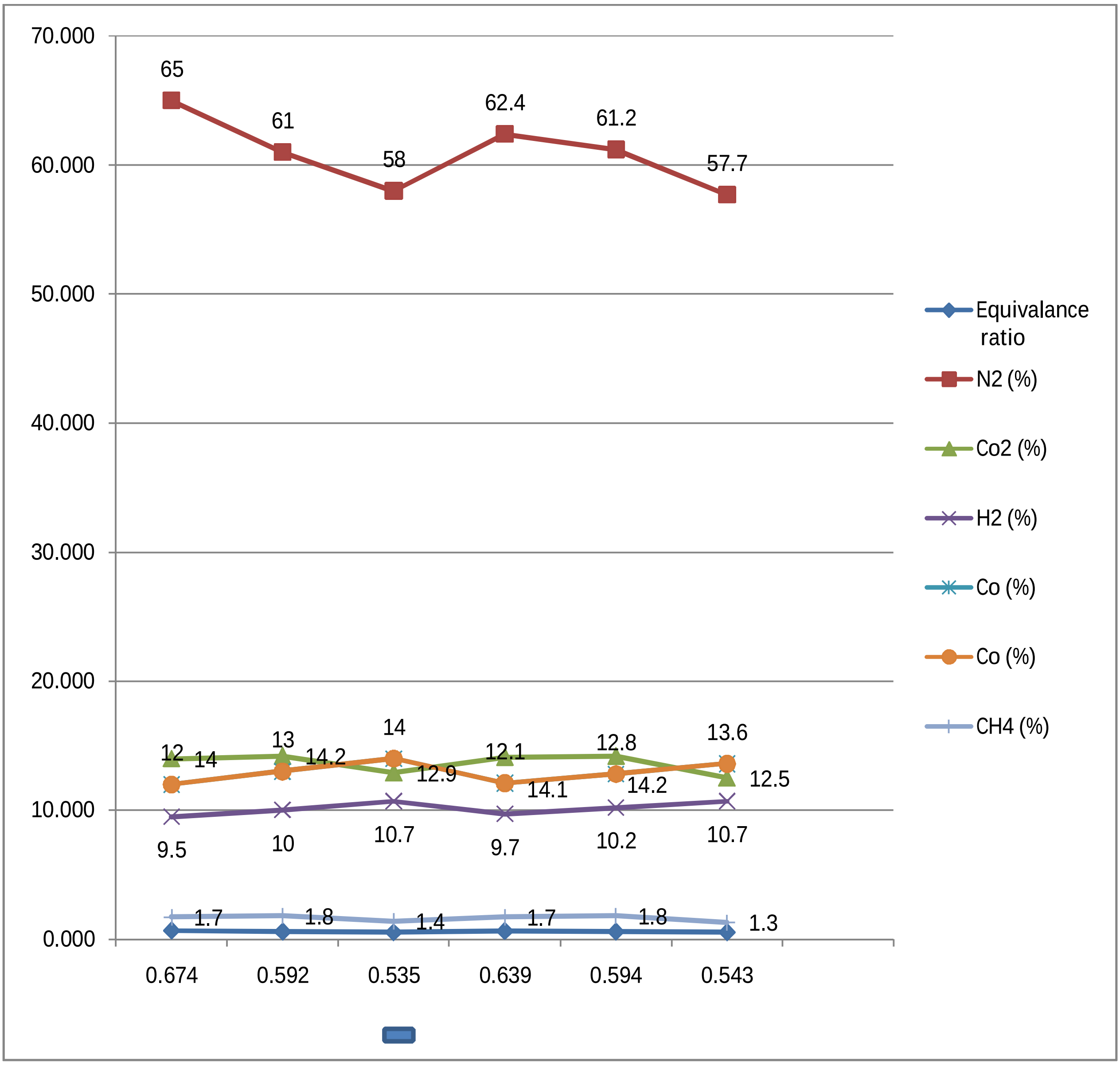

Fig 4.3.2 Shows the variation of GE, LHV, SFC, G/F against varying ER for 100% Rice husk briquette.

The fig 5.2.3 shows the variation in composition of producer gas with Equivalence ratio for 70% woody biomass+30% rice husk briquette & it observed that the percentage of CO2 -12.23%,Co-18.70%,H2-13.69% ,CH4-2.19% & rest N2 at the optimum Equivalence ratio of 0.36.

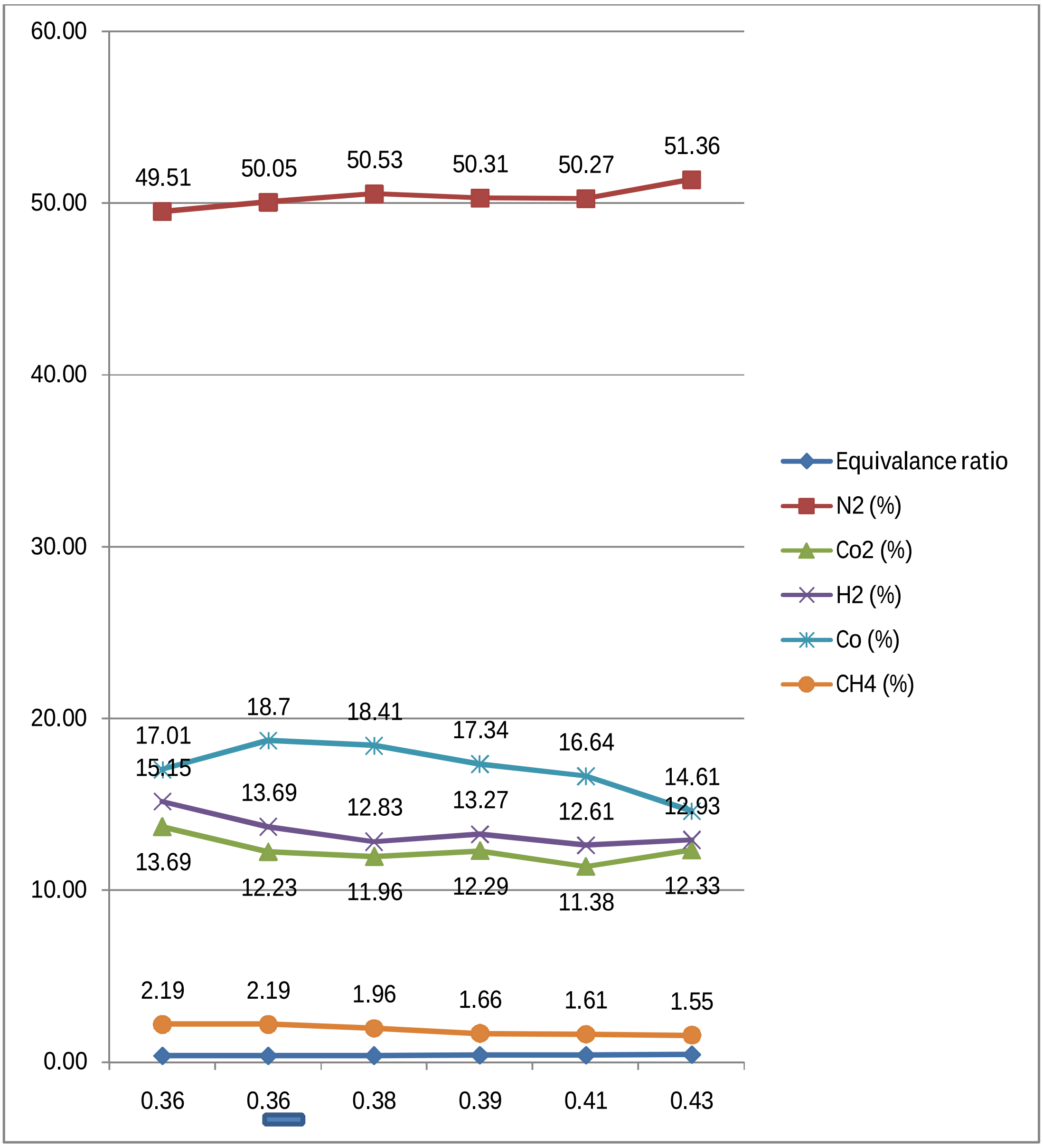

Fig 4.3.3 Shows the variation of GE,LHV,SFC,G/F against varying ER for70% woody biomass + 30% Rice husk briquette.

The fig 5.2.4 shows the variation in composition of producer gas with Equivalence ratio for 50% woody biomass+50% rice husk briquette & it observed that the percentage of CO2 -11.5%,Co-19.57%,H2-12.68% ,CH4-2.12% & rest N2 at the optimum Equivalence ratio of 0.36.

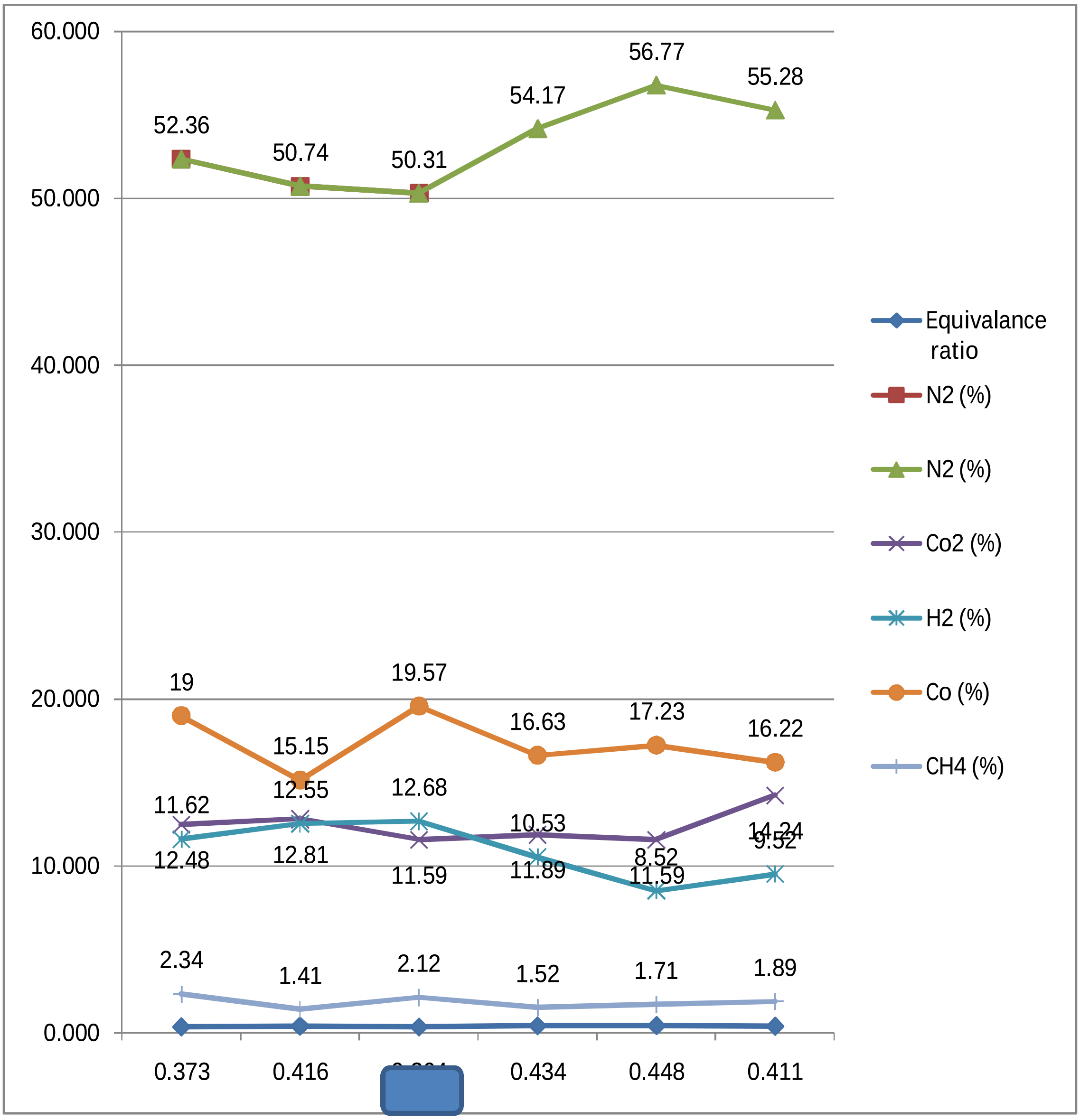

Fig 4.3.4 Shows the variation of GE,LHV,SFC,G/F against varying ER for 50% woody biomass + 50% Rice husk briquette.

4.4 COMPARASION OF PERFORMANCE BETWEEN VARIOUS BLENDS

4.4.1 LHV/ER

Fig indicates the graph between Equivalence ratio & low heat value of gas of 100% woody biomass, 70% woody biomass + 30% rice husk briquette , 50% woody biomass+50% rice husk briquettes & 100% rice husk briquettes & it is found that maximum value of low heat value of as generated is found in the equivalence ratio between 0.334 to 0.36 except for the rice husk .

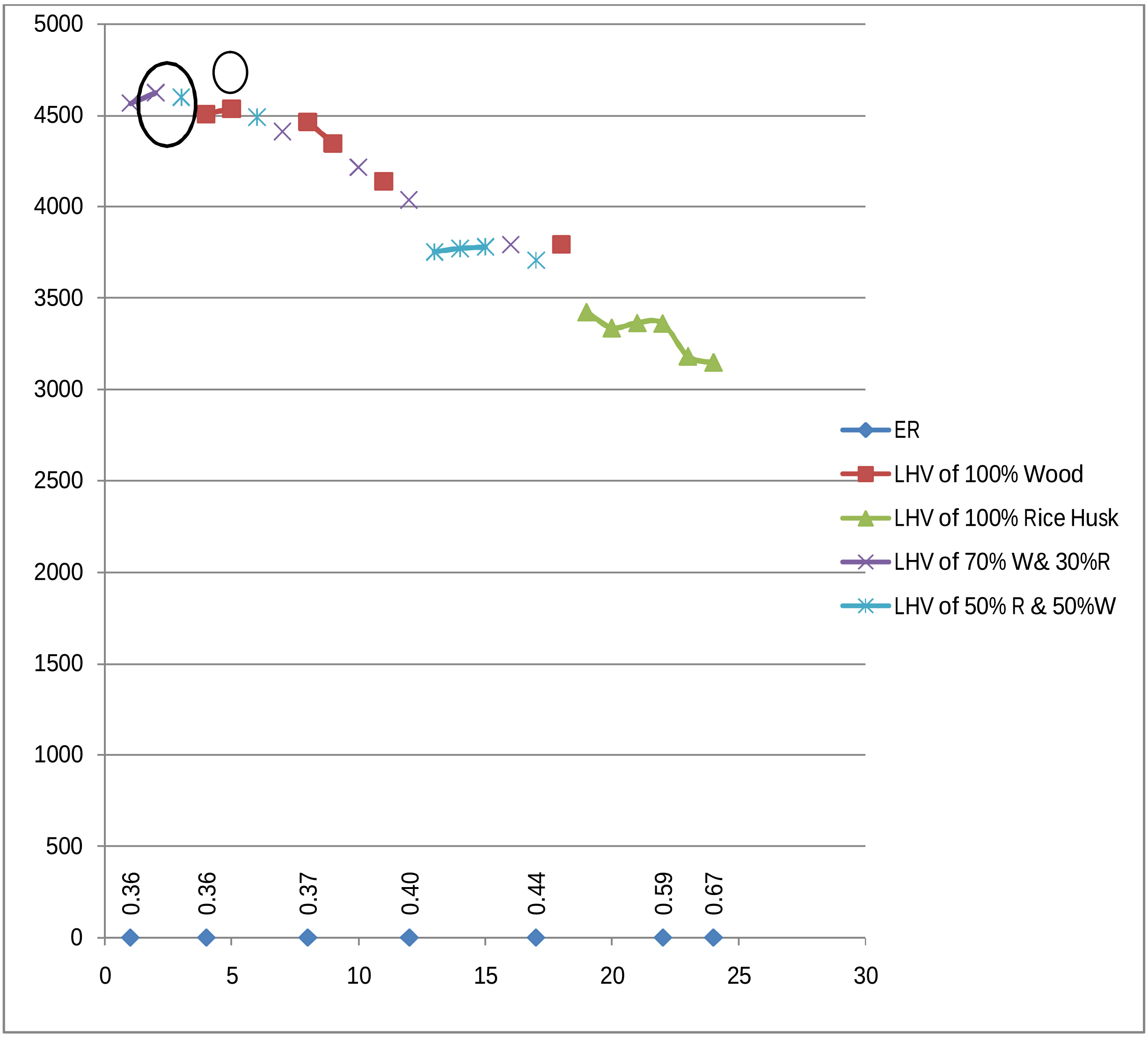

Fig 4.4.1 Shows the variation of LHV against varying ER for different blends of biomass

4.4.2 ER VS GASIFICATION EFFICIENCY

Fig 5.3.2 indicates the graph between Equivalence ratio & low heat value of gas of 100% woody biomass, 70% woody biomass + 30% rice husk briquette , 50% woody biomass+50% rice husk briquettes & 100% rice husk briquettes & it is found that maximum value of gasification efficiency value of as generated is found in the equivalence ratio between 0.334 to 0.36 . For rice husk it is high because of the high gas production due to high value of equivalence ratio.

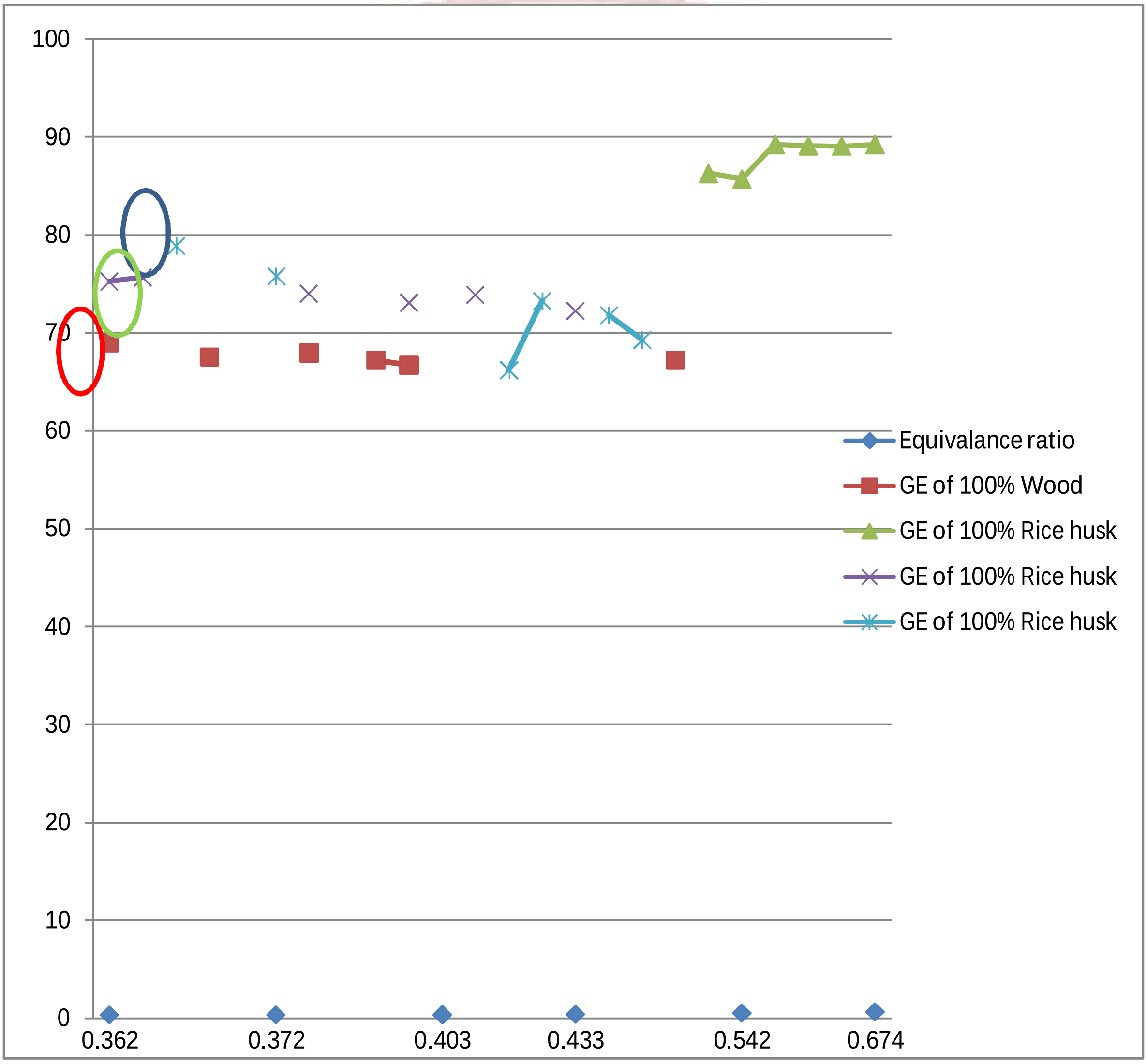

Fig 4.4.2 Shows the variation of GE against varying ER for different blends of biomass

4.5 FINAL RESULTS

Based on the data obtained during this study, following results were drawn.

There was a clear variation of performance of the gasifier with equivalence ratio for all blends of biomass having different bulk density & ash contentment.. Lower ash content of the mixe gives the better result in terms of equivalence ration & corresponding gas flow rate, low heat value of gas & finally the cold gasification efficiency which would ultimately gave better performance to reduce the specific fuel consumption while using the gas from this mixes on electrical load.

Optimum equivalence ratios for each blends of biomass having different ash content was found to be 0.33- 0.36 for 100% woody biomass, 70% woody+30% rice husk briquettes & 50% woody & 50% rice husk briquette and corresponding lower heating values of gas , cold gas efficiencies & gas production rate were 4.05-5.045 MJ/Nm^3 and 68-79% respectively except with 100% rice husk where these value were almost 0.54,3.5 MJ/Nm3, 3.72,& 83.3 respectively- because of the high ash content..The high values of gasification efficiency is because of the high production of gas rate due to high equivalence ratio of 0.54 showing it is actually not gasifying but combusting.

The gas compositions obtained for VARIOUS MIXES EXCEPT THE 100% RICE HUSK ALONE are comparable with typical producer-gas composition.

Fuel	Proportion Ratio	Avg Bulk Density in Kg/Cu.m	Ash Content in %	OPTIMUM ER	LHV in KJ/cu.m	Gasification Efficiency in %	SFC in kg/hr	G/F in Cu.m/hr
Wood	100%	450	4	0.33	5045	68.9	0.94	2.70
Rice husk + Wood	30%+70%	600	8.8	0.36	4622	75.70	0.95	2.93
Rice husk + Wood	50%+50%	700	12	0.36	4597	78.90	0.96	2.92
Rice husk	100%	950	20	0.54	3423	83.30	1.01	3.72

Table 4.5.1 shows Optimum Equivalence Ratio for max CV, LHV, Gasification Efficiency & Gas production rate of different blends

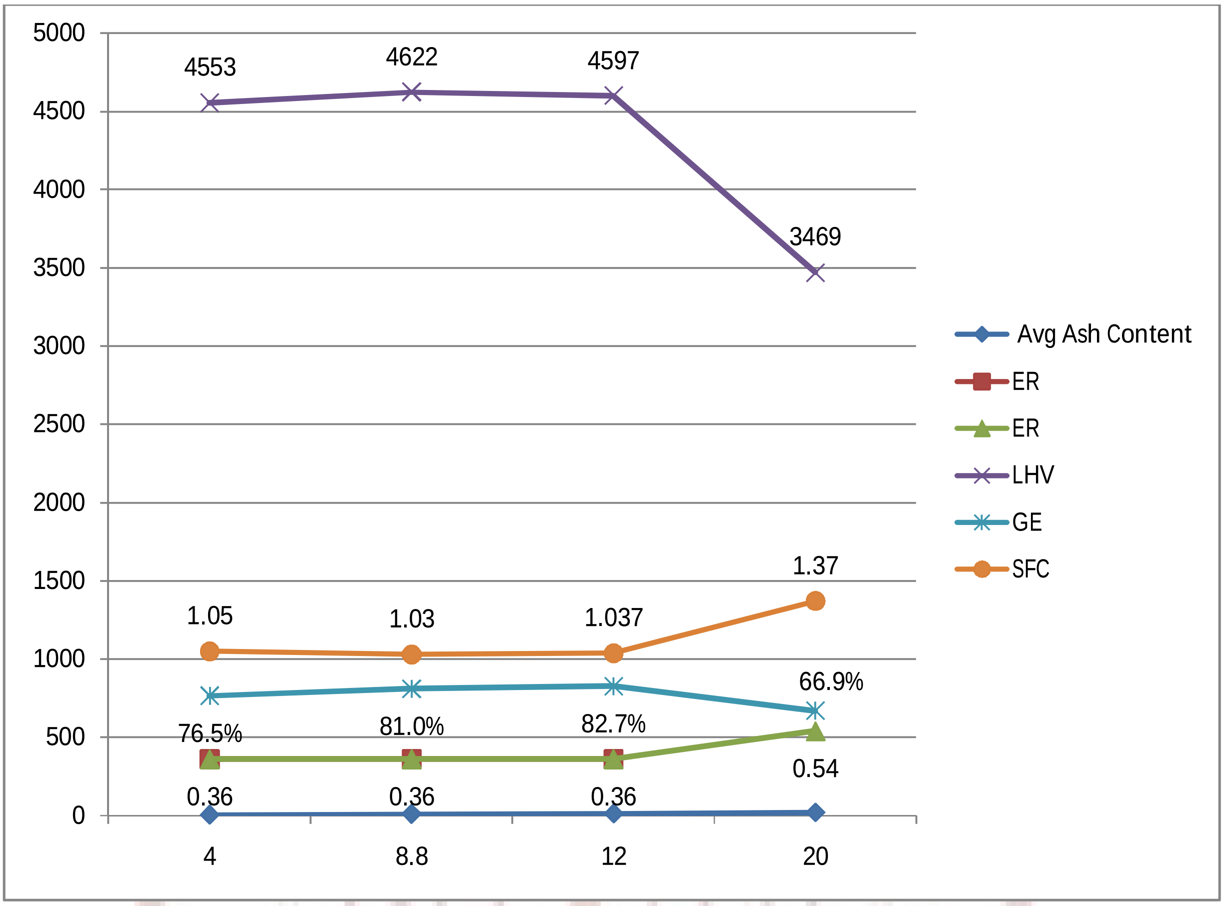

FIG: 4.5.1 shows Optimum Equivalence Ratio (0.334-0.36) for max CV, LHV, Gasification Efficiency & Gas production rate of different blends

4.6 Comparison of performance of earlier literature values with present work.

It is observed form the earlier work done previously that the results of the current study in terms of equivalence ratio, gasification efficiency & calorific value is quite comparable.

Group	Biomass Type	Optimum Equivalence Ratio	Calorofic value MJ/Nm3	Specific gas production in Nm3/Kg	Cold gas Efficiency in %
Dogru et al 2002	Hazzlenut shell	0.276	5.15	2.73	80.91
Zainal et al 2002	Furniture wood +Charcoal	0.388	5.34	-	80
Pratik et al 2009	Furniture Waste	0.205	6.34	1.62	56.87
Ummadisingu et al 2010	Wood Shaving	0.21	6.14	1.75	45
Gunaratne	Rubber wood	0.356	4.75 (LHV)	2.9	73.02
Present Study					
a)	wood 100%	**0.33**	**5.045**	**2.72**	**68.9**
b)	Rice husk 100%	0.54	**3.423**	**3.72**	**83.3**
c)	Wood 70% +Rice husk 30%	**0.36**	**4.621**	**2.93**	**75.7**
d)	Wood 50% +Rice husk 50%	**0.36**	**4.597**	**2.92**	**78.9**

5. CONCLUSION & RECOMMENDATIONS

The following conclusions were drawn from the results.

- Calorific value or cold gas efficiency and specific gas production are changing in inversely proportional manner. When large heat is required, low ER is to be used in which gas production is less & On the other hand when a large amount of gas is needed higher value of ER is recommended**.**

- The optimum equivalence ratio is found between 0.32-0.37 for different ash contents mixes but with the rice husk alone it is shifting towards combustion instead gasification with low heat value of gas about 3.500MJ/nm3. To get the optimum result from rice husk it is proposed to blend it with other biomass to keep the ash content maximum under 12%.

- For 100 % woody biomass, indicates that the max gasification efficiency of 69%, max low heat value of gas of 5054Kj/kg, lowest specific fuel consumption 1.01 kg/kwh with as production of about 2.72m3/kg is obtained at the equivalence ratio of 0.334 which is the optimum point after which as the equivalence ration increases, gasification efficiency, low heat value of gas decreases.

- For 70 % woody biomass + 30% rice husk briquette, indicates that the max gasification efficiency of 75.7%, max low heat value of gas of 4622KJ/kg, lowest specific fuel consumption 0.95 kg/kwh with as production of about 2.93m3/kg is obtained at the equivalence ratio of 0.334 which is the optimum point after which as the equivalence ration increases, gasification efficiency, low heat value of gas decreases.

- For 50 % woody biomass +50% rice husk briquette, indicates that the max gasification efficiency of 78.9%, max low heat value of gas of 4597KJ/kg, lowest specific fuel consumption 0.96 kg/kwh with as production of about 2.92m3/kg is obtained at the equivalence ratio of 0.334 which is the optimum point after which as the equivalence ratio increases gasification efficiency low heat value of gas decreases.

- For 100% Rice husk briquettes blend, indicates that the max gasification efficiency, max low heat value of gas, lowest specific fuel consumption is obtained at the equivalence ratio of 0.59 which is the optimum point after which as the equivalence ration increases, gasification efficiency, low heat value of gas decreases. The high gas production rate is because of high equivalence ratio. The reaction is shifting towards combustion to gasification.

- For 100% woody biomass & it observed that the percentage of CO2 -11.62%, Co-19.72%, H2-17%, CH4-2.1% & rest N2 at the optimum Equivalence ratio of 0.334.

- For 100% Rice Husk Briquette & it observed that the percentage of CO2 -12.90%,Co-14%,H2-10.2% ,CH4-1.4% & rest N2 at the optimum Equivalence ratio of 0.535.The composition shows the reactor is behaving badly in terms for gasification.

- For 70% woody biomass+30% rice husk briquette & it observed that the percentage of CO2 -12.23%, Co-18.70%,H2-13.69% ,CH4-2.19% & rest N2 at the optimum Equivalence ratio of 0.36.

- For 50% woody biomass+50% rice husk briquette & it observed that the percentage of CO2 -11.5%,Co-19.57%,H2-12.68% ,CH4-2.12% & rest N2 at the optimum Equivalence ratio of 0.36.

- For 100% woody biomass, 70% woody biomass + 30% rice husk briquette , 50% woody biomass+50% rice husk briquettes & 100% rice husk briquettes & it is found that maximum value of low heat value of as generated is found in the equivalence ratio between 0.334 to 0.36 except for the rice husk .

- For 100% woody biomass, 70% woody biomass + 30% rice husk briquette , 50% woody biomass+50% rice husk briquettes & 100% rice husk briquettes & it is found that maximum value of gasification efficiency value of as generated is found in the equivalence ratio between 0.334 to 0.36 . For rice husk it is high because of the high gas production due to high value of equivalence ratio.

- There was a clear variation of performance of the gasifier with equivalence ratio for all blends of biomass having different bulk density & ash contentment.. Lower ash content of the mixes gives the better result in terms of equivalence ratio & corresponding gas flow rate, low heat value of gas & finally the cold gasification efficiency which would ultimately gave better performance to reduce the specific fuel consumption while using the gas from this mixes on electrical load.

5.1 RECOMMENDATION FOR FUTURE:

PRESENT STUDY IS CARRIED OUT USING LOOSE AGRO RESIDUE IN THE FORM OF BRIQUETTE OF CERTAIN DENSITY, WITH OUT CONSIDERING THE EFFECT OF TAR IN THE GAS PRODUCED USING AIR AS OXIDIZER. ONE CAN CONTINUE THE STUDY.

- Using agro residue in its natural form with out converting the same into briquette to save the auxiliary load & manpower.
- Can experiment with high ash content fuel
- Using hot air , steam as an oxidizer
- Tar & particulate studies
- Study of activated char for increasing the iodine number
- Engine parameter studies
- Waste heat recovery for drying the biomass as well as for refrigeration purpose from genset.
- Generation of activated charcoal that can be extracted from char extraction conveyor has got the good value of iodine number that can be used as good fertilizer, as a purification agent & so on.

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7.0 RESUME

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I have completed about 30 Nos. of gasifier based power projects so far across India. Among them current working on 2 Mwe gasifier based power plant installed in Hubli for Pointec Pens &&energy, first of its kind in India.