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Performance Evaluation of High Pressure Down Draft Biomass Gasifier for BIG/GT Applications.

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Abstract :The increase of fossil fuel consumption and depletion in its reserves is making the investigations in the area of power production and new fuel research , for quest in alternate fuels for combined cycles. The main objective of any researcher in combined cycle is that to maximize the thermal efficiency and utilize best available fuel for power generation, which is alternate way for utilizing renewable source of energy. Gasification technologies with combined cycle operation are more viable operation and its utilization in gas turbines is one of the known technical challenges the researchers around the world are facing today. The present work deals with design, performance and operation of biomass down draft gasifiers operating at high pressure above atmospheric conditions on different biomass fuels. A 32 KW_e biomass down draft gasifier is designed and operated at high pressure and performance characteristics are presented for further review. Experiments were performed on the 32 KW_e downdraft biomass gasifier and results are presented.

Keywords—BIG/GT, BIGCC, Producer gas

I. Biomass

Photosynthesis by plants captures around 4,000 EJ/year in the form of energy in biomass and food. **Fischer** and **Schrattenholzer [1]** estimated the global biomass potential to be 91 to 675 EJ/year for the years 1990 to 2060 [1]. Their biomass included crop and forestry residues, energy crops, and animal and municipal wastes. **Hoogwijk [2]** estimated these to be 33 to 1135 EJ/year. Biomass included energy crops on marginal and degraded lands, agricultural and forestry residues, animal manure and organic wastes. **Parikka [3]** estimated the total worldwide energy potential from biomass on a sustainable basis to be 104 EJ/year, of which woody biomass, energy crops and straw constituted 40.1%, 36% and 16.6%, respectively. Only about 40% of potential biomass energy is currently utilized. Only in Asia, does the current biomass usage slightly exceed the sustainable biomass potential. Currently, the total global energy demand is about 470 EJ/year. Per lack estimated that, in the United States, without many changes in land use and without interfering with the production of food grains, 1.3 billion tons of biomass can be harvested each year on a sustainable basis for bio-fuel production. However, harvesting, collecting and storage of biomass adds another dimension of technical challenges to the use of biomass for production of fuels, chemicals and bio-power . Two main ways of converting biomass energy (solid fuel) into bio-fuels and bio-power are biochemical conversion and thermochemical conversion processes. Biochemical conversions convert the biomass into liquid or gaseous fuels by fermentation or anaerobic digestion. Fermentation of the biomass (starch and cellulose) produces primarily ethanol. Anaerobic digestion leads to the production of gaseous fuel primarily containing methane. The thermochemical conversion of biomass produces synthetic gas which is rich in hydrogen, carbon monoxide, methane. The definition of biomass encompasses numerous materials that may be converted into efficient fuels. These materials can be divided into the following:

1. Woody biomass (wood, branches, leaves etc)
2. Agricultural biomass and residues
3. Industrial processing residues
4. Dedicated energy crops
5. Animal wastes (manure, poultry litter)

As per the **Thomas Reed [5]**, context, biomass is defined as all renewable organic material, whether in the form of plant materials, animal manure, food processing, forest materials or urban wastes. Most of the above mentioned biomass contains cellulose, lignin, and hemicelluloses as main constituents. **Cellulose** is a linear polymer of anhydroglucose units; **hemi-cellulose** is a mixture of polymers of 5- and 6-carbon anhydrosugars, and **lignin** is an irregular polymer of phenyl propane units. In biomass, these three polymers form an interpenetrating system, or block copolymer, that varies in composition across the cell wall. Nevertheless, in large samples, there is a relatively constant atomic ratio of $CH_{1.4}O_6$. (The ratios will vary slightly with species. Coal is typically about $CH_{0.9}O_{0.1}$ but varies more widely in composition.) The relationship between solid, liquid, and gaseous fuels is easily seen in Fig.# , where the relative atomic concentrations of carbon, hydrogen, and oxygen are plotted for a variety of fuels. Here it is seen that the solid fuels, biomass, coal and charcoal, lie in the lower left segment of the diagram; liquid and gaseous hydrocarbon fuels lie in the upper left section; CO and Hz are joined by the bisector of the triangle; and the combustion products of fuels, C0, and H2O, lie on a vertical line on the right.

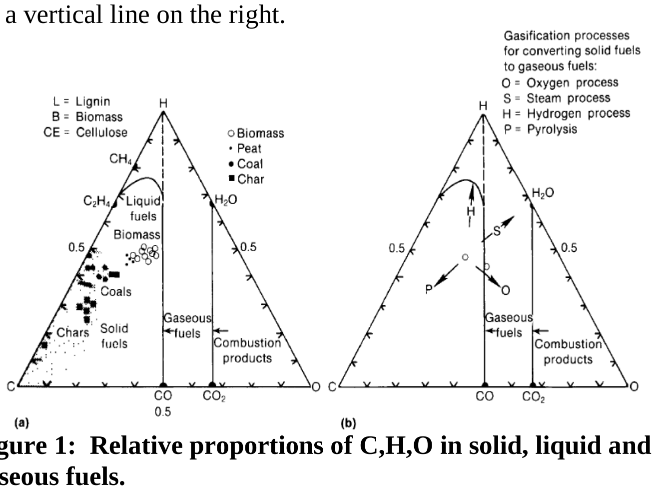

Figure 1: Relative proportions of C,H,O in solid, liquid and gaseous fuels.

Gasification processes convert biomass into combustible gases that ideally contain all the energy originally present in the

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biomass. In practice, conversion efficiencies ranging from 60% to 90% are achieved. Gasification processes can be either direct (using air or oxygen to generate heat through exothermic reactions) or indirect (transferring heat to the reactor from the outside). The gas can be burned to produce industrial or residential heat, to run engines for mechanical or electrical power, or to make synthetic fuels. Biomass gasifiers are of two types, updraft and downdraft gasifiers. In an updraft unit, biomass is fed in the top of the reactor and air is injected into the bottom of the fuel bed. The efficiency of updraft gasifiers ranges from 80 to 90 per cent on account of efficient counter-current heat exchange between the rising gases and descending solids. However, the tars produced by updraft gasifiers imply that the gas must be cooled before it can be used in internal combustion engines. Thus, in practical operation, updraft units are used for direct heat applications while downdraft ones are employed for operating internal combustion engines.

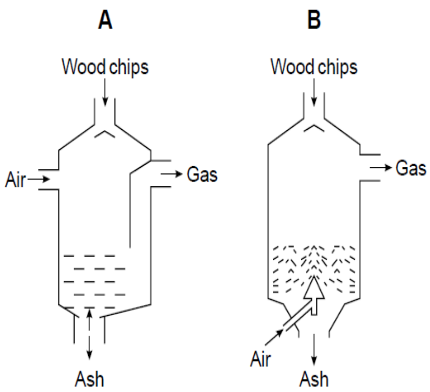

Figure 2: Schematic of updraft and downdraft gasifiers

Large scale applications of gasifiers include comprehensive versions of the small scale updraft and downdraft technologies, and fluidized bed technologies. The superior heat and mass transfer of fluidized beds leads to relatively uniform temperatures throughout the bed, better fuel moisture utilization, and faster rate of reaction, resulting in higher throughput capabilities.

II. LITERATURE REVIEW OF BIOMASS GASIFICATION

As per **K. Maniatis**[6], gasification is an energy process producing a gas that can substitute fossil fuels in high efficiency power generation, heat and or CHP applications, and can be used for the production of liquid fuels and chemicals via synthesis gas. However, for most of the applications the efficient and economic removal of tar still presents the main technical barrier to be overcome. **B.C. Jain** [7], explained the commercialization of biomass gasifiers in the world and in particular to India. He presented the constraints faced in commercializing bio-energy in general and biomass gasifiers in particular have been listed and conclusions drawn about where the programme in India is likely to go in the foreseeable future. **M.R. Nouni**et al [8], presented results of a techno-economic evaluation of biomass gasifier based projects for decentralized power supply for remote locations in India. **B.V.Babu** [9] et al has conducted experiments on down draft gasifier using Dalbergiasisoo, generally known as sesame wood or rose wood is mainly used in the furniture and wastage of the same is used as a biomass material. The resulting gas, known as producer gas, is more versatile in its use than the original solid biomass. Various researchers like **Mukunda** et al [11], have experimented on various biomass available and reported the experimental investigations. Biomass such as wood, bagasse, sugar cane, maize and switch grass are used widely all round the world. Downdraft gasifiers yield producergas with lower tar content (1-2 g/Nm3) than updraft gasifiers. **B.V.Babu** [9]et al at BITS , pilani has published work relates to thermodynamic modeling and simulation of down draft gasifiers and its advantages over updraft gasifiers. **Avdhesh Kr. Sharma** [10], conducted an experimental study on a 75 kWth, downdraft (biomass) gasifier system for obtaining temperature profile, gas composition, calorific value and trends for pressure drop across the porous gasifier bed, cooling–cleaning train and across the system as a whole in both firing as well as non-firing mode. **C.R. Purvis1** et al [12], described a new generation of small scale (less than 20 MWe) biomass fueled, power plants developed based on a gas turbine (Brayton cycle) prime mover. They stated that these power plants can be used to increase the efficiency and lower the cost of generating power from fuels like wood and agricultural wastes such as rice hulls, cotton gin trash, nut shells, and various straws, grasses, and animal manures. **S. C. Bhattacharya** et al **[13, 14, 15]**, summarized the prospects for biomass gasifiers for cooking application in Asia. Improved cook stove programme implemented in the developing world attempted to address these problems. **AyhanDemirbas**[16], described the potential applications of renewable energy sources to replace fossil fuel combustion as the prime energy sources in various countries, and discussed problems associated with biomass combustion in boiler power systems. However, for throated close-top downdraft biomass gasifier, commonly known as an Imbert downdraft gasifier, a complete model including pyrolysis, combustion and reduction zones has not been reported in the literature. In a survey of gasifier manufacturers, it is reported that 75% of gasifiers offered commercially were downdraft, 20% were fluid beds (including circulation fluid beds), 2.5% were updraft, and 2.5% were of other types indicated by **A.V.Bridgwater [20]**. Taking into account of the importance of downdraft biomass gasifier and its commercial applications, it is essential to have a complete model for such a configuration which indicates the pyrolysis, secondary tar reactions, homogeneous gas reactions and heterogeneous combustion/gasification reactions. Hence the various dimensions of Imbert type of downdraft gasifieris presented for usage of various types of biomass fuels.

III. THERMO-CHEMISTRY OF DOWNDRAFT GASIFICATION

Gasification is a highly complex chemical process. A.V.Bridgewater[20] described the gasification sequence as drying and evaporating processes of biomass followed by pyrolysis, and finally oxidation and reduction.Thermal conversion processes for biomass involve some or all of the following processes:

Pyrolysis: Biomass + Heat → Charcoal, oil, gas.
Gasification: Biomass + Limited oxygen → Fuel gas
Combustion: Biomass + oxygen → combustion Products

The gasification process usually takes place in a reactor with a restricted supply of air. Gasification (pyrolysis) can also be done by indirect heating (no air). This process is sometimes known as gasification by partial combustion or partial oxidation and depending on reactor type may have lower carbon conversion efficiency than combustion, producing a carbonaceous solid residue known as char. Gasification takes place at elevated temperatures under sub-stoichiometric conditions resulting in a typical equivalence ratio much greater than one. Because the gasification process takes place under sub stoichiometric conditions, the solid fuel is only partially oxidized and the thermo-chemical conversion yields a valuable energy carrier (known as a producer gas) that typically contains carbon monoxide, carbon dioxide, methane, hydrogen, nitrogen (especially if air is used as oxidant), other nitrogenous species, water, smaller amounts of lighter hydrocarbon gases, and varying amounts of tars, oils, acids, and other condensable. The gas may also contain entrained char and ash particles. Pyrolysis, which is the first step in gasification and solid fuel combustion, is the process of degrading or breaking down a material at elevated temperatures to produce oils, tars, char, and gases (e.g. CO, CO2, H2, H2O, CH4). A variety of oxidants can be used to complete the gasification process, including oxygen, air [21], steam [22] or a combination of these. An abbreviated gasification reaction for an organic fuel is as shown below in equation

$C_xH_yO_z + n_1H_2O + n_2(1+e)(O_2 + 3.76\ N_2) \rightarrow n_3CO_2 + n_4H_2O + n_5N_2 + n_6O_2 + n_7CO + n_8H_2 + n_9CH_4 + n_{10}C(s)$ + *other gases + tars, oils, acids.*

For subabul wood as the biomass fuel, the thermochemical conversion is given by

$C_1H_{1.4}O_{0.62} + n_1\ H_2O + m\ (O_2 + 3.76\ N_2) \rightarrow n_3\ CO_2 + n_4H_2O + n_5N_2 + n_6\ O_2 + n_7\ CO + n_8\ H_2 + n_9CH_4.$

The Intermediate reactions occurring in the gasification process are

Oxidation process: $C+O_2 \rightarrow CO_2$

Steam gasification process: $C + H_2O \rightarrow CO + H_2$

Bouduard reaction: $C + CO_2 \rightarrow 2CO$

Methanation reaction : $C+2H_2 \rightarrow CH_4$

Water Shift reaction: $CO + H_2O \rightarrow CO_2 + H_2$

Out of these only four reactions are independent reactions, which are chosen as oxidation, steam gasification, bouduard reaction, and the methanation reaction. The water gas shift reaction can be considered as the subtraction of the steam gasification and bouduard reactions. Oxidation reaction is typically assumed to be very fast and goes to completion (Von Fredersdorff and Elliott, 1963) and three reactions namely bouduard reaction, steam gasification and methanation are in equilibrium.

IV. DESIGN AND DEVELOPMENT OF HIGH PRESSURE GASIFIER

The design of the downdraft gasifier involves determining the amount of power needed to generate electricity, the amount of fuel to be supplied to the gasifier needed to meet the energy required for application. It computes the size of the combustion chamber in terms of diameter and height of the reactor.

A. The downdraft gasifier dimensions

1) Reactor Diameter

This refers to the size of the reactor in terms of the diameter of the cross-section of the cylinder where the fuel is being burned. This is a function of the amount of the fuel consumed per unit time (FCR) to the Specific Gasification Rate (SGR) of the fuel ranging from 100-250 kg m^{-2}-h. The reactor diameter is computed using the formula.

$$D= \sqrt{\frac{4*FCR}{SGR*\pi}}$$

The power output of the updraft gasifier is highly dependent on the diameter of the reactor. The bigger the diameter of the reactor, more is the energy that can be released by the gasifier. This also means more fuel is expected to be burned per unit time since the gas production is a function of gasification rate in kg of fuel burned per unit time per unit area of the reactor.

2) Height of reactor

This refers to the total distance from the top and the bottom end of the reactor. This determines how long would the gasifier be operated in one loading of fuel. Basically, it is a function of a number of variables such as the required time to operate the gasifier (T), the specific gasification rate (SGR) and the density of the fuel. As shown below, the height of the gasifier is computed using the relation:

$$H= \frac{SGR*T}{\rho\ Fuel}$$

Where ρ is density of fuel used in gasifier and T is time of operation in Hours. Time of operation is considered to be about 5 hrs. Hence the Height of Reactor is estimated to be about 2.5 mt. But the working height of the reactor is fixed 37.75% more in order to Provide socket and plug ,Accommodate grate and Provide space for Ash collection at the bottom.

3) Time to consume the fuel

This refers to the total time required to completely gasify the fuel inside the reactor. This includes the time to ignite the fuel and the time to generate gas, plus the time to completely burn all the fuel in the reactor . The density of the fuel (ρf), the volume of the reactor (Vr) and the Fuel Consumption Rate (FCR) are the factors used in determining the total time to consume the fuel in the reactor. This is computed using the relation:

T= ρ * Volume of Reactor/ FCR

4) Air flow rate (AFR)

This refers to the rate of flow of air needed to gasify the fuel. This is very important in determining the size of the fan or of the blower needed for the reactor in gasifying the fuel. This can be simply determined using the rate of consumption of the fuel (FCR), the stoichiometric air of the fuel (SA), density of air (ρa) and the recommended equivalent ratio (ε) for gasifying wood fuel of 0.3-0.5. This is obtained using the relation indicated below.

$$\text{Air flow rate} = \frac{\varepsilon*FCR*Stochiometric\ \ Air}{Density\ \ of\ \ air}$$

5) Superficial Air Velocity

This refers to the speed of the air flow in the fuel bed. The velocity of air in the bed of the fuel will cause channel formation which may greatly affect gasification. The diameter of the reactor (D) and the Air Flow Rate (AFR) determine the superficial velocity of air in the gasifier.

$$V_s = \frac{Air\ Flow\ Rate}{Area\ \ of\ \ Reactor}$$

B. Performance prediction parameters

1) Fuel Consumption rate

This is the amount of fuel used in operating the gasifier divided by the operating time. This is computed using the relation:

$$FCR = \frac{Weight\ of\ Fuel\ Used\ \ (Kg)}{Operating\ \ Time\ \ (Hr)}$$

2) Specific Gasification Rate

This is the amount of fuel used per unit time per unit area of the reactor. This is computed using the formula :

$$SGR = \frac{Weight\ of\ Fuel\ Used\ \ (Kg)}{Reactor\ \ Area\ \ x\ Operating\ \ Time\ \ (Hr)}$$

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3) Combustion Zone Rate (CZR)

This is the time required for the combustion zone to move down the reactor.

$$CZR = \frac{\text{Length of Reactor}}{\text{Operating Time (Hr)}}$$

4) Power input to the gasifier

This is the amount of energy supplied to the gasifier based on the amount of fuel consumed.

$$Power_{input} = FCR * (HHV)_{biomass}$$

5) Power output of gasifier

Power output is obtained from brake thermal efficiency of gas turbine. Power output is given by

$$Power_{output} = \text{Power rating of prime mover}/\eta \text{ brake}$$

6) Percentage of Char produced

This is the ratio of the amount of char produced to the amount of fuel used. This can be computed using the relation

$$\%\ Char = \frac{\text{Weight of Char Produced}}{\text{Weight of sawdust used}}$$

7) Gasifier Efficiency

It is defined as ratio of energy sought to energy supplied. The energy sought is in the form of HHV associated with the producer gas composition and Energy supplied is associated with Energy of Biomass.

V. Results

The gasifier used for biomass integrated gasification / Gas turbine cycle for power generation should be capable of supporting the prime mover with adequate quantity of gas at part load and full load operation. The gasifier / reactor dimensions are estimated as per the fluid flow and energy requirements and at various power requirements. The table 1 indicates the sizing of the reactor and air flow requirements of the gasifier.

At different power ratings of the gas turbine the size of gasifier is estimated. It is observed that air flow requirement increases linearly with increase in fuel consumption rate. To operate at variable loads the gasifier must provide higher air flow, which is taken care by 6 nozzles placed radially at combustion zone.

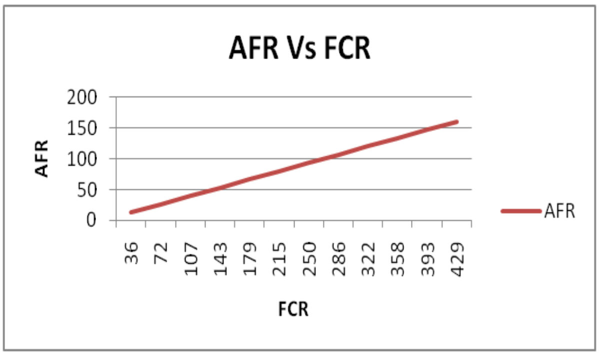

Figure 3: Air flow requirement Vs Fuel consumption rate

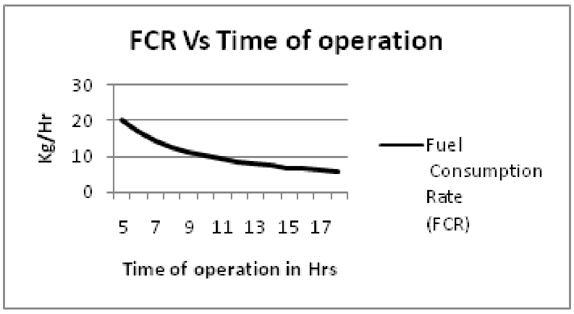

Figure 4: Fuel consumption rate

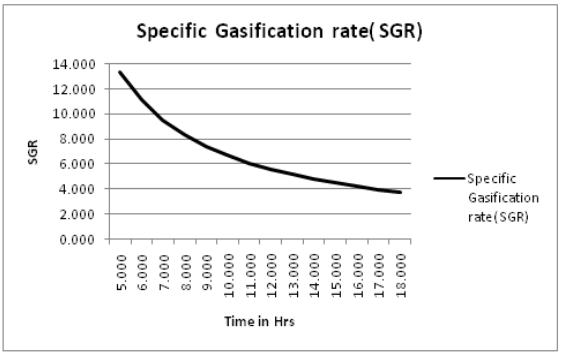

Figure 5: Specific Gasification rate

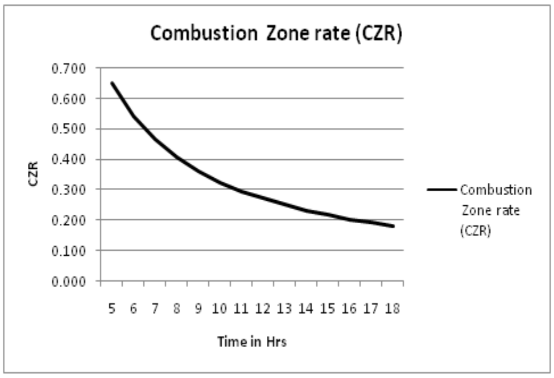

Figure 6: Combustion zone rate

It is noticed that the gasifier decreases as the CZR rate of the gasifier is decreased. This is observed experimentally at the end of operation of gasifier. This is indicated in the figure 7.

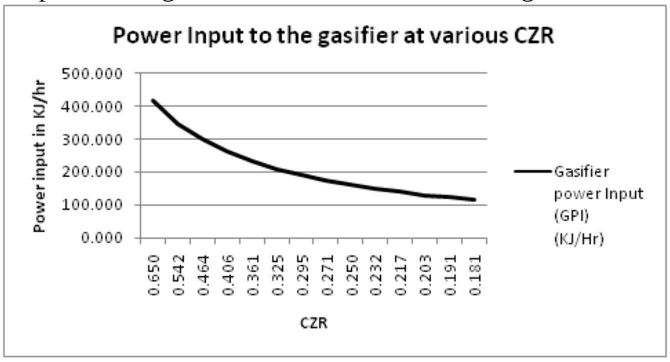

Figure 7: Power Input Vs CZR

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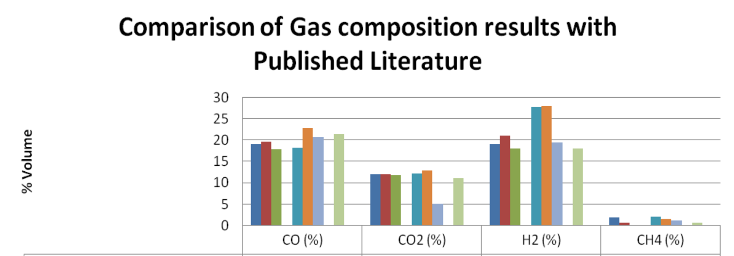
VI. Experimental Resultsof gasification

Experiments are conducted at room temperature of 34^0 C and relative humidity of 44 %. The biomass considered in the first set of experiment is sababul wood with a moisture content of 10%, 20 % and 30 %.The gasifier consists of bypass valve which allows air to the nozzles present in the oxidation zone and to the top of the gasifier. The air distributed through the nozzles is assisted for enhancing combustion of wood in the oxidation zone. The air is supplied through a centrifugal blower of 1 Hp capacity with a discharge of 2000 litres/hr.Experiment is repeated with 24, 26, 28 and 30 kg of wood with varying moisture content. Moisture content is varied by using freshly cut wood, partly dried and totally dried wood. The moisture content is determined by mass balance method, by measuring initial mass and final mass of wood (During drying process).The pressure in the gas pipe line is measured using differential manometer and velocity using Pitottube.The raw gas temperature is recorded as 193^0 C. The flow rate of gas is measured using a flow meter and 44 nm^3 / Hr is recorded. The quality of the gas is measured using CSL 704 make Gas chromatograph with porapak-N of 8 feet length column and molecular sieve 13 x, with argon as the carrier. Gas chromatography was used to determine the concentrations of CO, H2, CO2, CH4, N2 and O2 present in grab samples of a gas periodically collected throughout a run. The GC with TCD was calibrated on the composition shown in Table 3 and also calibrated with air (assumed 79 % v/v N2 and 21 % v/v O2).After each experiment, 100 µl samples were taken by syringe from 250 mL grab sample flasks and injected into the gas chromatograph. The Raw gas obtained after gasifier contains tar and alkaline sulphates. The gas is cooled in the cooler where water is supplied at 25^0C. It is direct contact type where water washes the gas there by it removes the suspended particles associated with the raw gas. This gas is then passed into scrubber, where the gas is locked by the water bed provided beneath the scrubber. Three stage centrifugal blowers are used to suck the cooled raw gas and tar is removed in the process of centrifugal action. The gas is then passed into cyclone where high density suspended particles are removed by centrifugal action and clean gas without tar is passed into condenser. In condenser, any trace of water vapour associated with the producer gas is removed and it is passed through the final section of cleaning process, ie, filter. Gas composition measured with GC-MS at Center for Energy technology is reported as shown below.



	CO (%)	CO2 (%)	H2 (%)	CH4 (%)
Sridhar et al(2002)	19	12	19	2
Zainal et al(2001)	19.61	12.01	21.06	0.64
jarungthammachote and dutta (2003)	17.86	11.84	18.04	0.11
Shashikantha (1988)	18.24	12.17	27.65	2.06
Channiwala (1992)	22.72	12.85	27.91	1.58
Present simulation (Simulation)	20.62	5.03	19.48	1.31
Experimental	21.33	11.1	18	0.79

Figure 8: comparison of gas composition with published literature

A. Effect of drying zone temperature

The temperature in the drying zone of the downdraft gasifier is recorded by the thermocouples placed at the top of the gasifier. The drying zone corresponds to about 200 mm from the top where the biomass is dried. Most of the moisture in the biomass is dried here and thermal cracking ie. Pyrolysis is observed in the post region of drying. The maximum temperature 550^0 C is observed. The gasifier is so designed that the gases leaving the gasifier during the initiation of gasification comes out from the bottom and move in the upward direction. This will heat the outer surface of the gasifier and provide necessary temperature for drying. It is observed that gasification of wood has yielded the product gas composition after a start uptime of 1 Hr and peak drying zone temperature is indicating the process of gasification.

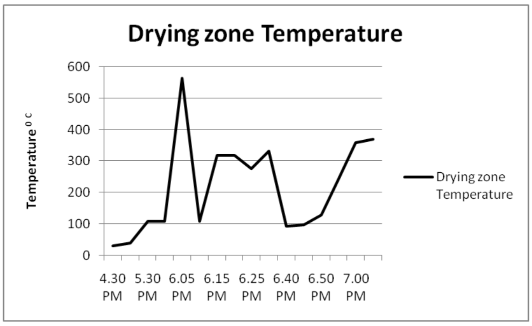


Figure 9: Drying zone Temperature

B. Effect of combustion zone temperature

The post drying zone involves pyrolysis and oxidation zones, which refer to near combustion zone and combustion zone. The temperature distribution near 200mm , 650 mm and 1100 mm from the combustion zone are recorded by the thermocouples and represented in the figure 5-14. The thermo gravimetric analysis of woody biomass indicates about 70% reduction in mass in this zone, where temperatures are about 250^0 C. after a time of one and half hour from the start of gasifier the drop in temperatures in this zone is observed, which indicates that the biomass feed is completely burnt and the gasifier is starving from the biomass.

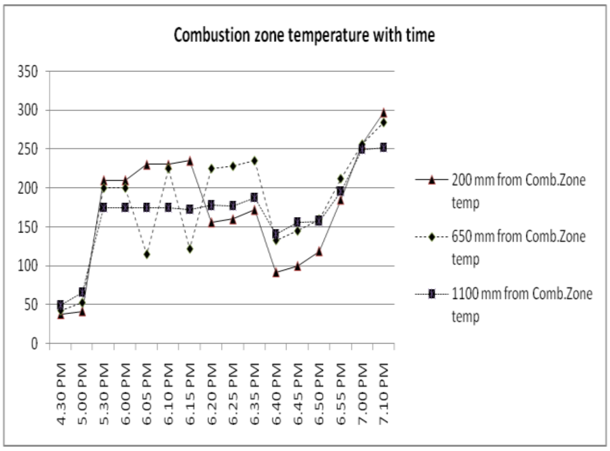


Figure 10: Combustion zone temperature

C. Effect of gasification zone Temperature

The gasification zone temperature is more importance as the product gas composition is dependent mostly on the gasification zone temperature. The variation of gasification zone temperature is indicated in figure 5-17. Two particular plots are made. The colored plot indicates the actual readings and it is best fit with 6th order polynomial. The gas yield starts when the gasification zone reaches a temperature of about 600^{0}C and it continues till it reaches a gasification temperature of about 800^0 C and above. The calorific value of the product gas increases from 600^0 C to approximately 800^{0}C and above which the calorific value reduces which is indicated in the figure .

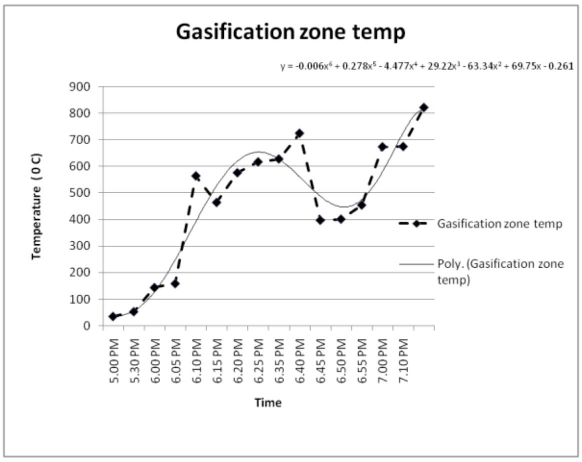


Figure 11: Gasification Zone Temperature

VII. CONCLUSIONS

As subabul wood is having less moisture content than the available biomass such as cotton stalks , ground nut shells, it can be used as a suitable fuel for power generation using BIG/GT technology. Maximum temperature of 550^{0}C is observed in the drying zone of the gasifier which corresponds to a distance of 200mm from the top of the gasifier. The fresh feed added after an hour has reduced the drying zone temperature and it was maintained at about 370 ^{0}C . The combustion zone temperature reaches a maximum of 1000 ^{0}C within 1 hr operation of the gasifier. The combustion temperature is stabilized at this maximum temperature for about 50 minutes for a feed rate of 25 Kg/Hr of subabul woody biomass. When the gasification zone temperature is 600^{0}C , the gas yield starts and continues till the gasification zone temperature reaches a maximum of 800^{0}C and above. The LCV of the yield gas increases from 600^{0}C to 800^{0}C and beyond which it decreases, Hence gasifier is to be operated at gasification zone temperature varying between 600^{0}C to 800^{0}C, where the estimated calorific value of the fuel is 7.19 MJ/Nm3. Raw producer gas is obtained at a temperature of 200^{0}C with contaminants such as soot , Tar , NH_3 and other higher compounds of Hydrocarbons, whose Molecular weight is greater than Molecular weight of benzene. The Tar levels in the operation of gas turbines should be lower than 5mg/Nm^3 of the gas. Hence in down draft gasifier the level of the Tar is less when compared to operation of updraft gasifier. Due to scrubbing and passage through cyclone, the tar associated with the product gas is separated and the gas obtained is clean and free from contaminants. It is observed that specific gasification rate (SGR) and combustion zone rate is decreasing as the time of operation of gasifier is increasing. Hence the High pressure gasifier designed is operated at a pressure of 1.1 bar to 3 bar absolute, with superficial velocity of 1.54 m/sec is reported.

VIII. ACKNOWLEDGEMENTS

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