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Syngas Production By Updraft Biomass Gasifer And Its Parametric Analysis

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***ABSTRACT*: *In today`s scenario of depleting conventionalfuels, biomass provides an alternate source of energy. Gasification is a chemical process that converts carbonaceous materials like biomass into useful convenient gaseous fuels or chemical feedstock. The product gas of gasification has a calorific value unlike that of complete combustion process.The present study is going to be focused on parametric analysis and study of the mathematical model to predict the effect of usage of various types of fuels in gasification process. The gasification process will be simulated using thermodynamic model using MATLAB and EES. Different fuels namely coal, rice husk and wood pallets will be studied. The analysis of syngas produced can be done by gas chromatography and Orsat apparatus. The simulation will be focused on the effect of pressure, air to fuel ratio and steam to fuel ratio on produced syngas composition. An experimental model which can hold a batch of 30kg fuel has been fabricated to take trial and study the process of gasification. Arrangements have been made so as to control the air flow, record the core, gas and steam temperature. Steam is generated within the setup in the water jacket and supplied to gasification process.*

Keywords* – *Gasification, Syngas, Parametric analysis, Mathematical modelling, Pyrolysis

I. INTRODUCTION

Today industrialization has lead to an increasing need of fuels. It is estimated that almost 80% of the worldwide energy needs are satisfied by fossil fuel [1]. Due to their limited nature it is the foremost need today to exploit other environmentally cleans inexhaustible sources of energy. Biomass provides such other alternative. Gasification is one of the technologies to harness the biomass energy and the equipment used is known as gasifier. PrabirBasu[2] has studied various types of gasifiers along with their advantages and disadvantages. C Higman and Marteen[3] have extensively studied the gasification's reactions and their kinetics. Reed and Das [4] have discussed the gas composition for various fuels and for various operating conditions. T Shrinivisan[5] has extensively discussed the effect of various operating parameters on the composition of syngas. The present work makes a practical working of an Updraft Biomass Gasifier apparatus, produces syngas in significant quantities and analyses its composition and heating value. Also a parametric analysis of the input parameters of the gasifier is done to inspect its effects on the composition and heating value of syngas produced. The detailed study of the methods of proximate and ultimate analysis for fuels viz. coal, wood pellets, rice husk and biomass is to be done. Parametric analysis of syngas on basis of variation of air-fuel ratio, pressure, oxygen content and temperature is also analysed.

I.1 Gasification Theory

Gasification is the conversion of solid or liquid feedstock into useful and convenient gaseous fuel or chemical feedstock that can be burned to release energy or used for production of value-added chemicals. A typical biomass gasification process may include the following steps:

- Drying
- Thermal decomposition or pyrolysis
- Partial combustion of some gases, vapours, and char
- Gasification of decomposition products

The gaseous product is commonly known as "SYNGAS" or "PRODUCER GAS" mainly containing hydrogen, carbon monoxide, carbon dioxide, water vapour, methane and some amount of unburnt carbon. Main gasifying agents are air, oxygen and steam.

II. ADVANTAGES OF GASIFICATION OVER COMBUSTION

1. Emission of sulfur and nitrogen oxides, precursors to acid rain, as well as particulates from gasification are reduced significantly due to the cleanup of syngas.
2. The particulates in the raw syngas are also significantly reduced due to multiple gas cleanup systems used to meet gas turbine manufacturers' specifications.
3. Furan and dioxin compounds are not formed during gasification. The lack of oxygen in the reducing environment of the gasifier prevents formation of free chlorine from HCl and limits chlorination of any precursor compounds in the gasifier. High temperature of gasification processes effectively destroys any furan or dioxin precursors in the feed

PROCESS AND REACTIONS IN UPDRAFT GASIFIER

As the fuel moves down in the gasifier it passes through various reaction zones namely drying, pyrolysis and

FEATURES	**GASIFICATION**	**COMBUSTION**
Purpose	• Creation of valuable, usable products from waste or lower value material	• Generation of heat or destruction of waste
Process Type	• Thermal and chemical conversion using no or limited oxygen	• Complete combustion using excess oxygen (air)
Raw Gas Composition (before gas cleanup)	H_2, CO, H_2S, NH_3, and particulates	CO_2, H_2O, SO_2, NO_x, andparticulates
Gas Cleanup	• Syngas cleanup at atmospheric to high pressures depending on the gasifier design • Treated syngas used for chemical, fuels, or power generation • Recovers sulphur species in the fuel as sulphur or sulphuric acid • Clean syngas primarily consists of $H_2$and CO	• Flue gas cleanup at atmospheric pressure • Treated flue gas is discharged to atmosphere • Any sulphur in the fuel is converted to SO_2that must be removed using flue gas cleanup systems, generating a waste that must be landfilled. • Clean flue gas primarily consists of CO_2 and H_2O
Ash/char or slag handling	• Low temperature processes produce a char that can be sold as fuel. • High temperature processes produce slag, a non-leachable, non-hazardous material suitable for use as construction materials. • Fine particulates are recycled to gasifier. In some cases fine particulates may be processed to recover valuable metals.	• Bottom ash and flyash are collected, treated, and disposed as hazardous waste in most cases.
Temperature	1300°F – 2700°F	1500°F – 1800°F
Pressure	Atmospheric to high	Atmospheric

gasification.

II.1 Drying Zone:

Here the biomass gets dried due to heat and moisture present in the fuel converts to steam:

$$Main\ Feedstock + Heat \rightarrow Dry\ Feedstock + H_2O$$ [3]

II.2 Pyrolysis Zone:

Pyrolysis is a thermo chemical decomposition of biomass into a range of useful products, either in the total absence of oxidizing agents or with a limited supply that does not permit gasification to an appreciable extent. It is one of several reaction steps or zones observed in a gasifier. During pyrolysis, large complex hydrocarbon molecules of biomass break down into relatively smaller andsimpler molecules of gas, liquid, and char. It takes place at a temperature greater than 2500C.[2]:

$$Dry\ Feedstock + Heat \rightarrow Char + Volatiles$$

II.3 OxidationorCombustion Zone:

An oxidation or burning zone is formed in the section where air/oxygen is supplied. These combustion reactions are highly exothermic and cause a rapid temperature increase up to 1100-1500^{0}C. The reactions are as follows [2,3]:

$$C + O_2 \rightarrow CO_2 \left(+393\ {}^{MJ}/_{kg\ mole}\right) \quad (1)$$

$$2H_2 + O_2 \rightarrow 2H_2O \left(+242\ {}^{MJ}/_{kg\ mole}\right) \quad (2)$$

II.4 Reaction Zone:

This is the main zone of gasifier where we get the product or Syngas. The reactions are as follows:

$$C + O_2 \rightarrow 2CO \quad \left(-164.9\ {}^{MJ}/_{Kg\ mole}\right) \quad (3)$$

$$C + H_2O \rightarrow CO + 2H \quad \left(-122.6\ {}^{MJ}/_{Kg\ mole}\right) \quad (4)$$

$$CO + H_2O \rightarrow CO_2 + H_2 \left(+42.3\ {}^{MJ}/_{kg\ mole}\right) \quad (5)$$

$$C + 2H_2 \rightarrow CH_4 \left(+75\ {}^{MJ}/_{kg\ mole}\right) \quad (6)$$

$$CO + 3H_2 \rightarrow CH_4 + H_2O \left(-205.9\ {}^{MJ}/_{kg\ mole}\right) \quad (7)$$

The mixture of gases produced in this zone is called Syngas or producer gas.

III. SIMULATION AND RESULT ANALYSIS

Thus the solutions of the gasification equations for coal simulated using MATLAB are CO (5.75%), CO_2 (30.55%), H_2 (10.97%), H_2O (14.53%), CH_4 (4.62%), N_2 (33.57%). Also it can be seen that the percentage of CH_4 is less which is the basis objective of gasification. The gasification was carried out for unit weight of steam per kg of fuel required.The variation of air supply on the gas composition is shown in graph 1. It can be seen that with an increase in supplied air there is a decrease in percentage of H2, CO and CO2 while that of N2 increases.

Variation of pressure also causes a change in gas composition. As seen from the graph with an increasing pressure, there is increased percentages of CO2 and N2 while the percentage of H2 and CO decreases. The same can be seen from graph 2. Steam feed rate variation causes change in gas composition as well. Increased steam rate from zero causes an increase in hydrogen produced. Graph 4 shows the effect of increased steam rate on syngas. Increased air supply causes increased CO2 production which decreases the lower calorific value of the syngas. The same variation can be seen from graph 3.The stimulation results comply with the ASPEN stimulation and other literature data [5].

IV. GRAPHS FROM SIMULATION

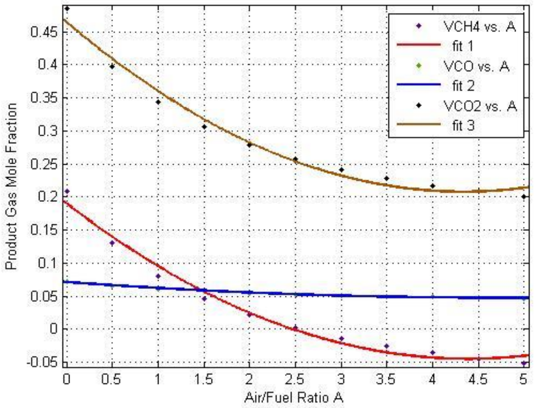

Fig 2: Product gas mole fractions versus Air to fuel ratio

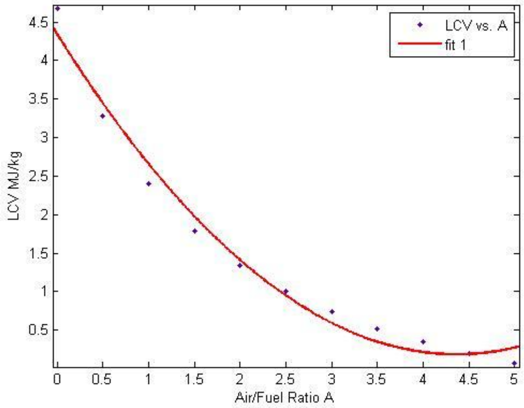

Fig 3: Low Calorific Value versus Air to fuel ratio

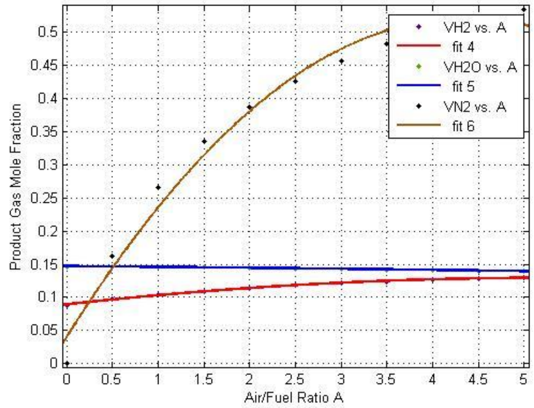

Fig 4: Product gas mole fractions versus Air to fuel ratio

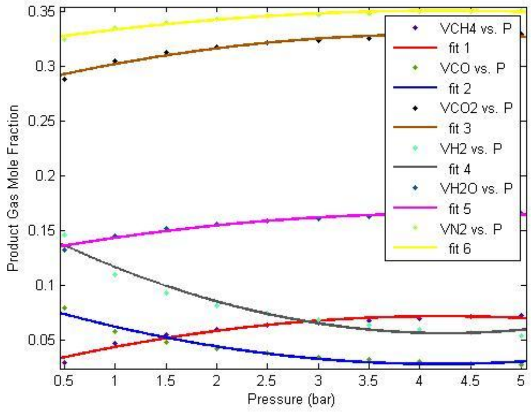

Fig 5: Product gas mole fractions versus Pressure

V. ANALYSIS OF FUELS

V.1 Analysis of Coal

V.1.1 Proximate Analysis

The proximate analysis of coal was developed as a simple means of determining the distribution of products obtained when the coal sample is heated under specified conditions. As defined by ASTM D 121, proximate analysis separates the products into four groups: (1) moisture, (2) volatile matter, consisting of gases and vapors driven off during pyrolysis, (3) fixed carbon, the nonvolatile fraction of coal, and (4) ash, the inorganic residue remaining after combustion. Proximate analysis is the most often used analysis for characterizing coals in connection with their utilization. The actual method of analysis is described below:

V.1.2 Ultimate Analysis

The ultimate analysis indicates the various elemental chemical constituents such as Carbon, Hydrogen, Oxygen, Sulphur, etc. It is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design etc.

Table 1. Typical Proximate Analysis of various Coals (percentage)

Parameter	Indian Coal	Indonesian Coal	South African Coal
Moisture	5.98	9.43	8.5
Ash	38.63	13.99	17
Volatile Matter	20.70	29.79	23.28
Fixed Carbon	34.69	46.79	51.22

Table 2. Typical Ultimate Analyses of Coals

Parameter	Indian Coal, %	Indonesian Coal, %
Moisture	5.98	9.43
Carbon	41.11	58.96
Hydrogen	2.76	4.16
Nitrogen	1.22	1.02
Sulphur	0.41	0.56
Oxygen	9.89	11.88

Table 3. Proximate Analysis data of selected biomass materials [6]

Dry	Wheat		Rice		Cotton	Wood
	Straw	Bran	Straw	Husk		
Volatile	69	70	59	66	72	84
Fixed Carbon	23	22	19	17	24	16
Ash	8	8	21	18	4	0.3

Table 4. Ultimate Analysis data of selected biomass materials [6]

	Wheat		Rice		Hay	Cotton Stalks	Wood
	Straw	Bran	Straw	Bran			
C	45.7	47.7	39.2	44.5	45.9	46.6	48.6
H	5.7	6.4	4.8	6.3	6.0	5.6	6.1
O	43.3	42.0	36.4	36.9	39.4	42.8	45.0
N	0.5	2.8	0.4	0.9	2.3	0.7	0.2
S	0.3	0.3	0.2	0.6	0.3	-	-
Cl	0.7	-	1.9	-	1.0	0.5	<0.1

VI. DETAILS OF EXPERIMENTAL SETUP

For every trial the gasifier apparatus has to be properly setup for the efficient running. The whole of the apparatus has to be thoroughly cleaned by wire brush before trial is taken. After the whole setup is cleaned, the base of the gasifier also called as the trough is filled with gravel and sand mixture for the making of fluidized bed. On top of this gravel a layer of ash is put. The water jacket is completely filled with water which helps in formation of steam by absorbing the excess heat. The air distributor is connected to the air inlet port. The distributor is connected to the ½ HP blower. Two sensors are connected to record steam temperature and output gas temperature.

Once everything is prepared, the fuel is heated outside the gasifier until it turns red hot. This red hot batch is put inside the gasifier from the top inlet. Two such batches are input to the gasifier and the top is closed by means of hopper and bolts. Afterwards, the fuel is partially burnt outside and fed through the hopper. Three such batches are added. After some time, the gas outlet is tested for SYNGAS production by placing a lighted matchstick.

After it is confirmed that SYNGAS is produced, the gas is collected in the collection apparatus provided and taken for analysis for composition and calorific value.

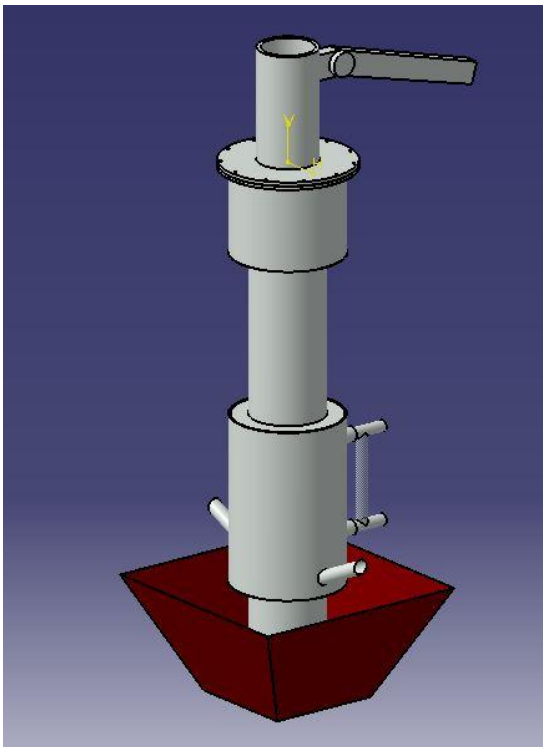

Fig 6: 3-D Diagram of Gasifier Apparatus

VII. SYNGAS TESTING METHODS

VII.1 Gas Chromatography

Gas chromatography (GC), is a common type of chromatography used in analytical chemistry for separating and analyzing compounds that can be vaporized without decomposition. Typical uses of GC include testing the purity of a particular substance, or separating the different components of a mixture (the relative amounts of such components can also be determined). In some situations, GC may help in identifying a compound. In preparative chromatography, GC can be used to prepare pure compounds from a mixture.[9][10]

VII.1.1 Construction and working

In gas chromatography, the mobile phase (or "moving phase") is a carrier gas, usually an inert gas such as helium or an unreactive gas such as nitrogen. The stationary phase is a microscopic layer of liquid or polymer on an inert solid support, inside a piece of glass or metal tubing called a column (a homage to the fractionating column used in distillation). The instrument used to perform gas chromatography is called a gas chromatograph(or "aerograph", "gas separator").

The gaseous compounds being analyzed interact with the walls of the column, which is coated with a stationary phase. This causes each compound to elute at a different time, known as the retention time of the compound. The comparison of retention times is what gives GC its analytical usefulness.

VII.2 Orsat Gas Apparatus[7,8]

An Orsat gas analyser is a piece of laboratory equipment used to analyse a gas sample (typically fossil fuel flue gas) for its oxygen, carbon monoxideand carbon dioxide content. Although largely replaced by instrumental techniques, the Orsat remains a reliable method of measurement and is relatively simple to use.It was patented before 1873 by Mr. H Orsat.

VII.2.1 Construction

The apparatus consists essentially of a calibrated water-jacketed gas burette connected by glass capillary tubing to two or three absorption pipettes containing chemical solutions that absorb the gasses it is required to measure. For safety and portability, the apparatus is usually encased in a wooden box.

The absorbents are:

- Potassium Hydroxide (Caustic Potash)
- Alkaline pyrogallol
- Ammoniacal Cuprous chloride

The base of the gas burette is connected to a levelling bottle to enable readings to be taken at constant pressure and to transfer the gas to and from the absorption media. The burette contains slightly acidulated water with a trace of chemical indicator (typically methyl orange) for colouration.

VII.2.2 Method of Analysis

By means of a rubber tubing arrangement, the gas to be analyzed is drawn into the burette and flushed through several times. Typically, 100mls is withdrawn for ease of calculation. Using the stopcocks that isolate the absorption burettes, the level of gas in the leveling bottle and the burette is adjusted to the zero point of the burette.

The gas is then passed into the caustic potash burette, left to stand for about two minutes and then withdrawn, isolating the remaining gas via the stopcock arrangements. The process is repeated to ensure full absorption. After leveling the liquid in the bottle and burette, the remaining volume of gas in the burette indicates the percentage of carbon dioxide absorbed.

The same technique is repeated for oxygen, using the pyrogallol, and carbon monoxide using the ammoniacal cuprous chloride.

VIII. CONCLUSION

1. For Indian coal, the following composition for SYNGAS was simulated:
   a. H2 = 8.8%
   b. CO = 41.8%
   c. CO2 = 0.623%
   d. H2O = 0.018%
   e. CH4 = 17.3%
   f. N2 = 32%
   g. CV = 12.59 MJ/kg
2. The effect of variation of parameters is as follows:
   a. With an increase in supplied air there is a decrease in percentage of H2, CO and CO2 while that of N2 increases.
   b. With an increasing pressure, there is increased percentages of CO2 and N2 while the percentage of H2 and CO decreases.
   c. Increased steam rate from zero causes an increase in hydrogen produced.
   d. Increased air supply causes increased CO2 production which decreases the lower calorific value of the syngas.

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