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AN ATMOSPHERIC BUBBLING FLUIDIZED BED BIOMASS GASIFIER

by

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Abstract

The development of and experiments carried out on a pilot plant fluidized bed biomass gasifier for the production of producer gas based on atmospheric air-blown gasification are discussed in this paper. The effect of operational parameters, such as, biomass feed rate, feed quality of biomass, gas flow rate and bed temperature, on the quality of the gas produced by the gasifier was studied in detail in this research work. Biomass wastes such as rice husk and saw dust of which particle sizes ranging from 0.5 to 6.0 millimetres, abundantly available in Sri Lanka were utilized in these experiments. It was aimed to recover a clean combustible gas of higher energy content by gasification rather than by direct combustion of biomass.

The pilot plant gasifier column having a square cross section with 230 mm side length of the bed and 3 m in height, produced combustible gas with a gas yield about 2.4 m^3 / kg of dry ash free fuel, which was suitable for a plant that requires thermal energy input of 200 kW. The produced gas generated from the gasifier needs only a little gas cleaning for tar removal as the heavy hot sand bed is the heat carrier. Tar deposition inside the gasification chamber is minimized due to the fluidization abrasion of hot sand bed.

In these experiments, combustible gas containing rich CO, CH_4 and H_2 compositions were obtained at bed temperatures from 600°C to 850° C, equivalence ratio from 0.2 to 0.35 and at the ratio of biomass flow rate to air flow rate from 0.28 to 0.45. The maximum concentration of gas was 6.22% H_2, 6.71 % CO, 5.07% CH_4 for rice husk having higher heating value of 4.27 MJ/Nm^3.

1.0 Introduction

Thermo-chemical gasification of biomass waste is the conversion of it by partial oxidation at elevated temperatures into a gaseous energy carrier containing carbon monoxide, carbon dioxide, hydrogen, methane, water vapour, nitrogen and trace amounts of higher hydrocarbons such as ethane and ethylene. Various contaminants such as small char particles, ash, tars and oils also exist in the gas produced. The partial oxidation can be carried out using air, oxygen, steam or a mixture of these (Bridgwater, 1995). Air gasification produces Nitrogen rich low energy gas whereas oxygen and /or steam gasification produces a gas of medium energy content.

Gasification of biomass is usually achieved in fixed beds, moving beds and fluidized beds. Fluidized bed technology offers several unique characteristics for biomass gasification. Gasification systems generally comprise fuel storage, handling and feeding systems, the gasifier, gas cooling and cleaning equipment and equipment for utilization of the producer gas. The fluidizing material is a mixture of sand and biomass. Sand acts as a inactive material for retention of thermal energy within the bed. The turbulent, fluidized state of sand particles in the bed creates an isothermal zone and enables accurate control of reaction temperatures.(Bridgwater, 1995). Generally bed temperatures should be controlled at 700°C for gasification and higher temperatures leads to complete combustion rather than gasification.

A grid network of a perforated plate is provided to ensure uniform distribution of the fluidizing material in the fluidized bed. Fluidization is accomplished by

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supplying a controlled flow rate of air through the distributor plate. When the feed material is introduced into the bed, it either fluidizes or settles on the bed according to its size and density. At this point the feed material is in contact with hot inert materials within the bed, resulting in rapid heating and pyrolysis of the feed materials. The gases from the oxidation reaction process are effectively mixed with the fluidized bed inert material. This improves the flow of gases to and from the hot solid surface of the bed materials (Sofer and Zaborsky,1981).

The higher velocities usually carry ashes and char out of the chamber together with the gas, which are generally separated in the cyclones. Producer gas is suitable for onsite applications as it is of low energy density. If it is directly used for thermal applications such as a boiler or a dryer, the gas can be fed to the user after cyclones without further cleaning or cooling. However if it is used for power generation in an IC engine, the gas should be processed for removal of tar and moisture.

A pilot plant fluidized bed gasifier for biomass abundantly available as wastes in Sri Lanka was designed, constructed, commissioned and evaluated of its performance. Conditions of a fluidized bed gasifier for producing combustible gases is primarily studied. Production of enriched quality combustible gases with low nitrogen contents, possible liquid chemical products such as ethanol, and decentralised power generation would be the long term benefits anticipated in this project.

A pilot scale fluid bed gasifier of square cross section 230 mm (230 mm , and 3m in height was constructed and tested for evaluating the dependence of quality of producer gas on various proportions of fluidizing materials and raw materials. Factors affecting for the optimum quality of the producer gas were also evaluated.

2.0 Plant layout & Safety issues

The plant layout shown in **Figure 1** consists of a root type air blower(A), fluidized bed reactor(B) with a feeder (C) for conveying solids into the gasification chamber.

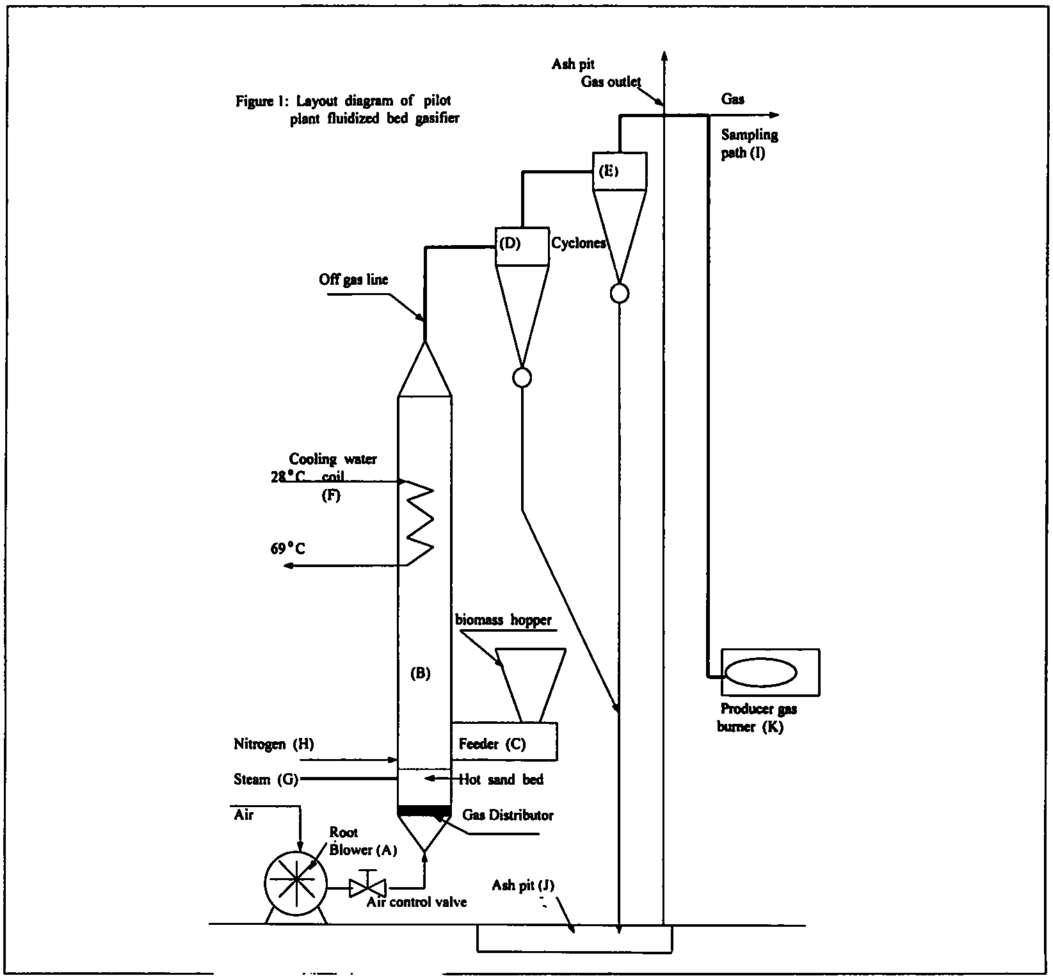

Figure 1: Layout diagram of pilot plant fluidized bed gasifier

Two numbers of high flow rate cyclones (D & E) were designed and fabricated for separation of ash particles from the producer gas. Facilities for gas cooling(F) and steam injection(G) into the fluidized bed were incorporated. The off-gas temperature was designed in order to have a value below the maximum permissible temperature of carbon steel (i.e. 540°C) by cooling water coil (F) fixed within the entrainment space of chamber. A burner for burning producer gas(K) is also selected as an auxiliary equipment. An ash pit(J) for collection of ash was also provided. An outlet port (I) was also included for withdrawal of gas samples for analysing.

The gasifier column, outlet pipe and cyclones were insulated with a refractory lining of high alumina castable concrete layer (HAC). The total thickness of the refractory lining was 70 mm. A root type blower capable of blowing air at a pressure of 25 kPa and a flow rate of 0.03m^3/s was used for supplying fluidizing air.

Carbon monoxide is a main component (approximately 5 to 10 mole %) of the producer gas from the fluidized bed gasifier and this gas is toxic. Therefore possible places of leaking the gas such as, the ash pit, the biomass feeder, the plunges and joints and the furnace were designed and fabricated to minimise the inhaling of producer gas as both the concentration and the duration exposure of workers to CO are important. A chimney outlet was designed from the ash pit to release the gases to the atmosphere, as the places above the 7 feet from the base working level was considered as harmless. A lock hopper system was fabricated to avoid the back flow of CO through the biomass feeding path. In order to prevent explosion in starting up a Nitrogen gas supply (H) was included for purging the system.

3.0 Materials & Methods

Biomass materials used for these experiments were rice husk of particle size ranging from 0.3 mm to 0.6 mm and saw dust of the particle size 0.3 mm to 0.5 mm. Feeds were prepared by sieving and sun drying. The hopper of the feeder was filled with a known amount of selected type of biomass. A known amount of sand of the size 0.3 mm to 0.5 mm was filled into the gasifing chamber. When the chamber and the sand bed was preheated up to the temperatures 700°C, air was introduced according to a previously selected air flow rate. Biomass was fed on to the hot fluidizing bed as shown in the **Figure 1.** At each trial the flame behaviour was observed at the producer gas burner fitted at the end of the gas line.

The gasifier was operated continuously until the system reached steady state conditions. At the steady state conditions aspiration of producer gas samples was initiated. The bed temperature and free board temperature were continuously recorded by thermocouples connected to the reactor at different heights.

The study involved varying the biomass feed rate, air flow rate and the height of the sand bed and the reactor temperature and gas composition was then monitored. Saw dust and rice husk were used as biomass materials. In these tests the air flow rate was adjusted to be between 0.003 and 0.05 kg/s.

The height of the sand bed was varied from 0.0254m(1") to 0.108m(4.25") at six different stages. Lower sand beds were selected, so that the root blower could deliver sufficient air to fluidize the biomass and sand mixture. Biomass feeding was carried out onto the top of the fluidizing hot sand bed at a height of 0.6m from the distributor.

4.0 Results and discussion:

In the gas analysis measurement CO, CH_4 and H_2 compositions were considered as important as these gases leads to enrich the producer gas giving continuous flame conditions at the producer gas burner. But composition of other hydrocarbons such as C_2H_6, C_2H_4 also recorded. But comparing with the CO, CH_4 and H_2 gas compositions C_2H_6, C_2H_4 concentrations were low at all selected conditions. It was noticed that results of tests were more or less same for both type of biomass. The results vary little with the sand bed heights and type of biomass. However, increasing the sand bed height increases the bed pressure drop and pressure required for fluidizing. For fluidizing higher sand beds, higher air blowing capacity was required.

The typical operational parameters for saw dust and rice husk gasification, the higher concentrations of CO, CH_4 and H_2 gas conditions obtained in these trials are shown in **table 1 and table 2.**

For the higher ratios of biomass feeding rate/air flow rate the producer gas enriches the concentration of CO, CH_4 and H_2 and continuous flame was observed for both biomass. This is shown in **Figure 2.** The rate of biomass feeding appreciably affected the gas composition at higher air flow rates giving poor quality of producer gas. Due to the pressure inside the gasification chamber the biomass feed rate was not sufficient for fast fluidizing conditions such as biomass/air ratios lower than 0.2 .

Table 1

Typical operational parameters and results for some gasification experiments for gasification of saw dust.

Run number	TSD1.5	TSD2.0
Feed stock	Saw dust	Saw dust
Moisture		
(% by weight on wet basis.)	15.3	18.0
Particle size(mm)	0.3 to 0.5	0.3 to 0.5
Feed rate(kg/hr)	24	19
Air flow rate(kg/s)	0.0157	0.0157
Minimum fluidization	0.086	0.086
Velocity (m/s)		
ER	0.5	0.7
H/C	1.85	1.92
O/C(including the air)	1.61	1.84
Gasifier		
Bed temperature °C	602	535
Free board temp. °C	455	530
Solid in bed	Sand	Sand
Particle size(mm)	0.3 to 0.5	0.3 to 0.5
Height of bed(fixed, m)	0.0381	0.0508
Expanded bed height(m)	0.0404	0.0538
Gasifier exit		
Gas composition (% by volume on dry basis)		
H_2	7.3	7.1
CO	6.75	5.9
CO_2	7.2	6.7
CH_4	4.42	3.5
C_2H_4	0.04	1.7
C_2H_6	0.03	1.3
HHV(MJ/Nm^3	3.44	4.19
Gas yield		
(Nm^3 /kg of dry ash free saw dust)	2.1	2.3

Table 2

Typical operational parameters and results for some gasification of rice husk experiments.

Run number	TRH2.0	TRH2.5
Feed stock	Rice husk	Rice husk
Moisture		
(% by weight on wet basis	18.1	17.3
Particle size(mm)	0.5 to 6.0	0.5 to 6.0
Feed rate(kg/hr)	15	24
Air flow rate(kg/s)	0.0157	0.0157
Minimum fluidization	0.071	0.071
velocity (m/s)		
ER	0.7	0.5
H/C	2.13	2.11
O/C(including the air)	3.11	2.53
Gasifier		
Bed temperature °C	500	857
Free board temp. °C	514	717
Solid in bed	Sand	Sand
Particle size(mm)	0.3 to 0.5	0.3 to 0.5
Height of bed(fixed, m)	0.0508	0.0635
Expanded bed height (m)	0.0538	0.0673
Gasifier exit		
Gas composition (% by volume dry basis)		
H_2	3.12	6.22
CO	5.9	6.71
CO_2	7.1	7.9
CH_4	3.13	5.07
C_2H_4	0.32	0.314
C_2H_6	1.48	0.912
HHV(MJ/Nm^3)	3.45	4.27
Gas yield		
(Nm^3 /kg of dry ash free husk)	2.6	2.8

The equivalence ratio, Hydrogen /Carbon ratio, Oxygen/Carbon ratio were calculated using following equations.

Air-to-fuel weight ratio used / Air-to-fuel weight ratio of stoichiometric combustion	(air flow rate/solid flow rate)/ stoichiometric air fuel ratio (0.0157/0.007083)/4.36 = 0.508365
Total number of the atom-g of hydrogen / Total number of atom-g carbon fed to the gasifier	(hydrogen feed rate with solid and moisture)/ carbon feed rate with solid = (0.000184+0.000446) / (0.001511) = 1.85
Total number of the atom-g of oxygen / Total number of atom-g carbon fed to the gasifier	(oxygen feed rate with air, moisture, solid)/ carbon feed rate with solid = (0.00166+0.00010 + 0.00163 +0.0029)/ (0.00367) = 1.61

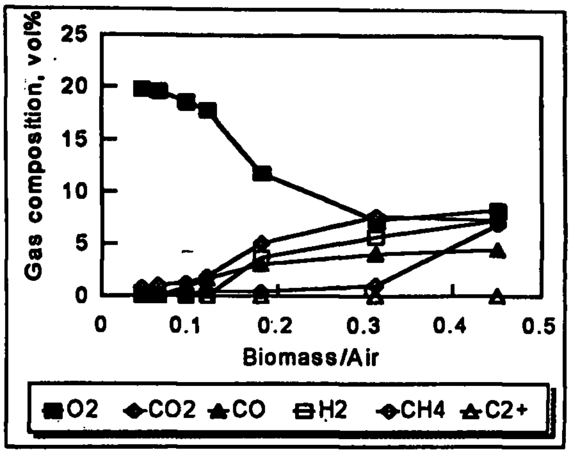

Figure 2: Variation of gas composition with the ratio of biomass to air flow rates. Condition is at 0.0381m (1.5") sand bed height, saw dust at moisture content at 15.3%

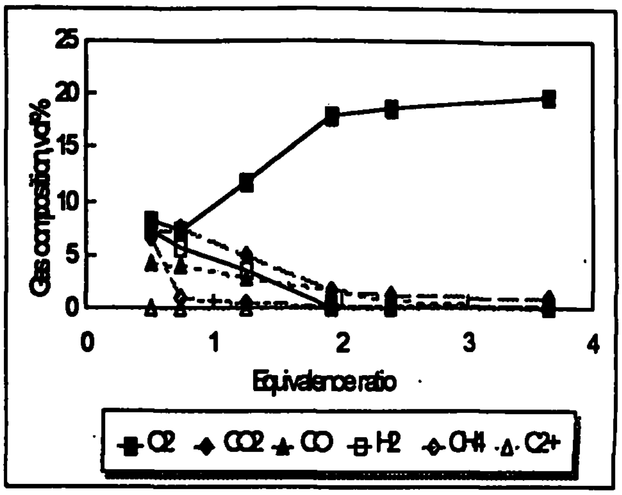

Figure 4: Variation of the gas composition with equivalence ratio for bio-mass. Condition is at 0.0381m (1.5") sand bed height, saw dust at moisture content at 15.3%

The calculated range for equivalence ratio (ER) was 0.5- 6.35 for gasification of both types of biomass. Only for the lower equivalence ratio value i.e. 0.5 to 0.7 test conditions, a continuous flame was observed at the producer gas burner. In the case of rice husk, increasing equivalence ratio, within the interval studied for ER (from 0.5 to 3.0) the amount of gases (H_2, CO, CH_4 and C_2H_6, C_2H_4) was found to decrease. The maximum amount of H_2, (6.22%) (table 2) for instance, is obtained at the minimum ER(0.5), for bed temperature at 857oC and free board at 717oC. For saw dust, in the interval studied for ER (from 0.2 to 6.35), the maximum amount of H_2, (7.3%) (table 1) for instance, was obtained at the minimum ER(0.5), for bed temperature at 602°C and free board at 455°C. Variation of the bed temperature with the ER is shown in **Figure 3**. The variation of gas composition with the ER is shown in the **Figure 4**.

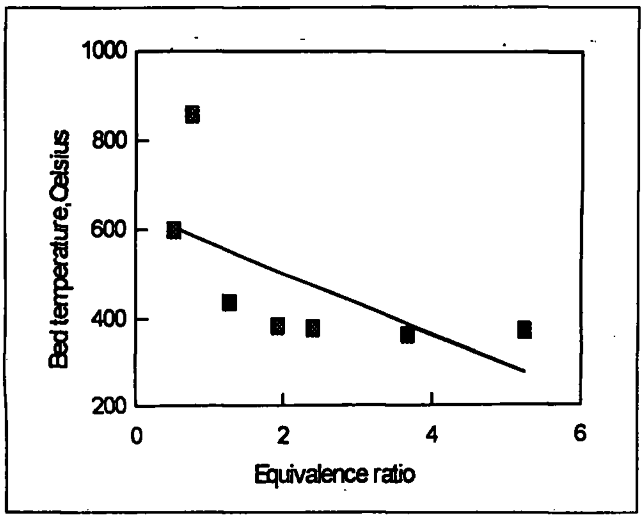

Figure3: Variation of the bed temperature with equivalence ratio for saw dust. Condition is at 0.0381m(1.5") sand bed height, saw dust at moisture content at 15.3%

During the study it was observed that the concentration of the fuel gas (C_2H_4, C_2H_6, CO, CH_4 and H_2) increase with the bed temperature in the gasifier. The variation of the gas composition with the bed temperature is shown in **Figure 5**. Higher concentration of CO, CH_4 and H_2 was observed at the bed temperatures around the range of 600°C to 700°C. The bed temperatures for gasification of rice husk should be in the range 700°C to 850°C.

The effect of bed temperature on the higher heating value of the producer gas (HHV) for rice husk gasification has been calculated, and it can be shown that the HHV increases with the bed temperatures(Figure 6). The HHV increases with bed temperatures due to the increase on the yields of C_2H_4, C_2H_6, CO, CH_4 and H_2. The effect of ER on the higher heating value of the producer gas (HHV) is shown that the HHV decrease with increasing ER as in the **Figure 7**.

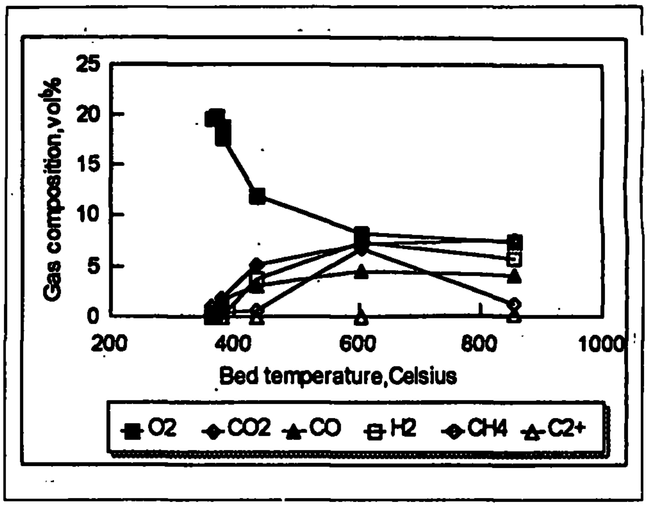

Figure 5: Gas composition of the raw gas produced at different bed temperatures. Condition is at 0.0381m (1.5") sand bed height, saw dust at moisture content at 15.3%

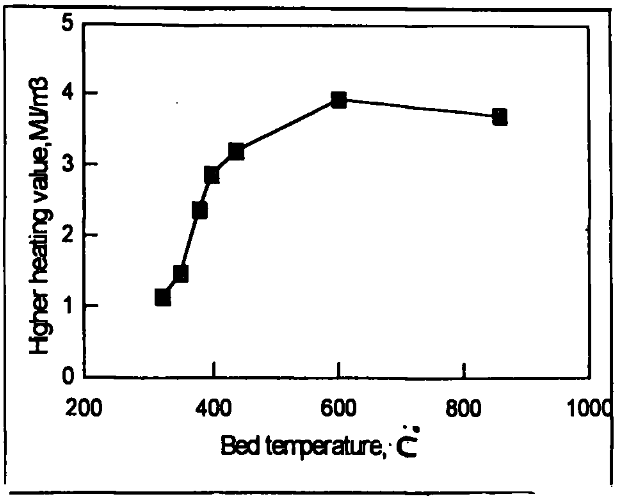

Figure 6: Variation of higher heating value with the bed temperatures. Condition is at 0.0381m (1.5") sand bed height, saw dust at moisture content at 15.3%

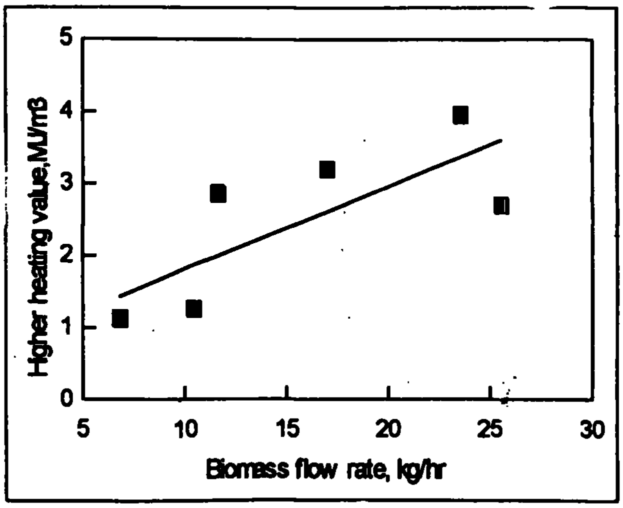

Figure 8: Variation of the higher heating value with the bio-mass flow rate

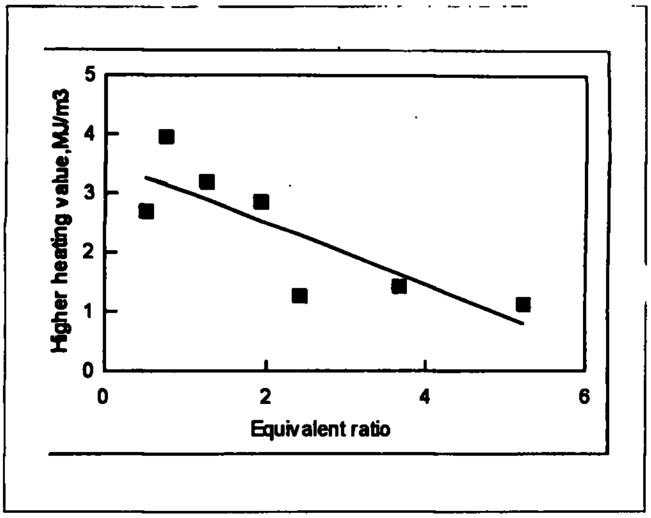

Figure 7: Variation of the higher heating value with the equivalence ratio

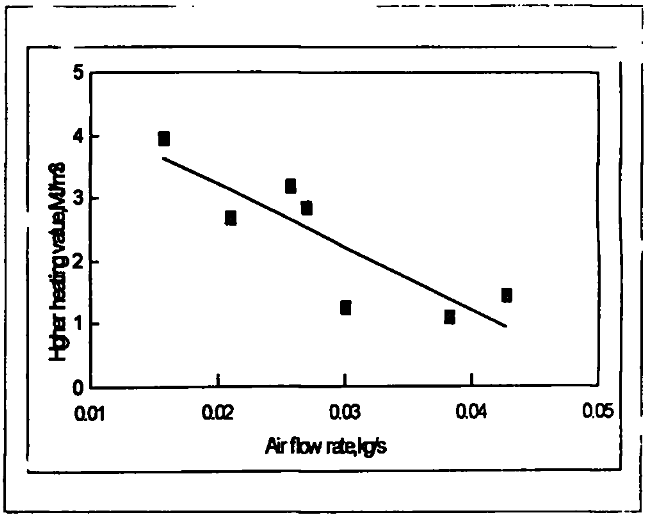

Figure 9: Variation of the higher heating value with the air flow rate

On increasing biomass flow rate from 15 kg/hr to 24 kg/hr, the heating value was seen to increase by about 1 MJ/Nm3 (positive effect) (**Figure 8**). With increasing air flow rate (**Figure 9**), the heating value was found to decrease by about 1 MJ/Nm3 (negative effect). This was found to be true for both types of biomass.

5.0 Conclusions

Fuel gas composition was considerably varied with changing the variables studied in this experiments for the pilot plant gasifier, having gasification chamber dimensions of 0.23m x 0.23m x 2.5 m. The variation of gas composition with the sand bed height was not significant. However increasing the sand bed height increases the bed pressure drop and pressure required for fluidizing. For fluidizing higher sand beds, the capacity of air blower should be higher.

Equivalence ratio (ER) is the most important factor in biomass gasification with air. In practice, it defines the temperatures of the bed and of the freeboard, gas composition and calorific value of the gas. On increasing ER from 0.2 to 0.7, the heating value decreases by about $1MJ/Nm^3$ (negative effect).

The biomass/air ratio is a measure of the combustible fraction inside the gasifier and is a very important variable in biomass gasification. It improves the quality of the raw gas produced. on increasing biomass/air ratio from 0.3 to 0.4 the heating value increases by about $1 MJ/Nm^3$

In order to obtain a raw gas with a good quality (maximum heating value) for feeding rice husk over the bed, it can be recommended that equivalence ratio to be around 0.50- 0.70; biomass/air around 0.3; bed temperature in excess of $700\,^{\circ}C$.

In order to obtain raw gas with a good quality (maximum heating value) while feeding saw dust over the bed, it can be recommended that ER be around 0.50- 0.70; biomass/air around 0.3; bed temperature less than 700 ° C.

In deciding optimal conditions for higher CO, CH_4 and H_2 gas concentrations, it can be concluded that a fluidized bed biomass gasifier should operate at biomass to air ratio around 0.3 to 0.4 and temperature of the gasifier bed 600°C to 850°C for rice husk and saw dust. In this series of experiments optimal conditions were obtained at the equivalence ratio from 0.5-0.70.

6.0 References

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