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Effect of Equivalence Ratio on Performance of Fluidized Bed Gasifier Run with Sized Biomass

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***Abstract*—Recently, fluidized bed gasification becomes an attractive technology for power generation due to its higher efficiency. The main objective pursued in this work is to investigate the producer gas production potential from sized biomass (sawdust and pigeon pea) by applying the air gasification technique. The size of the biomass selected for the study was in the range of 0.40-0.84 mm. An experimental study was conducted using a fluidized bed gasifier with 210 mm diameter and 1600 mm height. During the experiments, the fuel properties and the effects of operating parameters such as gasification temperatures 700 to 900 °C, equivalence ratio 0.16 to 0.46 were studied. It was concluded that substantial amounts of producer gas (up to 1110 kcal/m^3) could be produced utilizing biomass such as sawdust and pigeon pea by applying this fluidization technique. For both samples, the rise of temperature till 900 °C and equivalence ratio of 0.4 favored further gasification reactions and resulted into producer gas with calorific value 1110 kcal/m^3.

***Keyword*—Sized biomass, fluidized bed gasifier, equivalence ratio, temperature profile, gas composition.

I. Introduction

AGRICULTURAL residues are potentially an attractive feedstock for producing energy as their use contributes little or no net carbon dioxide to the atmosphere [1]. Major agricultural crops in the state of Gujarat are: Wheat, bajra, rice, maize, groundnut, mustard, sesame, pigeon pea, green gram, gram, cotton, and sugarcane. Presently, the most conventional way of handling these waste streams is to burn them with energy recovery or for landfilling. However, both combustion and landfill use cause secondary pollution problems. Novel disposal technologies are in high demand to provide for more energy efficient and environmentally and economically sound solutions. An alternative to these combustion and landfill uses is gasification. Biomass can be used as a solid fuel, or converted into liquid or gaseous forms, for the production of electrical energy, heat, chemicals or fuels. Biomass conversion technologies convert biofuels into a form usable for energy generation. Thermochemical gasification of biomass is a well-known technology that seems to be a feasible application and has been developed for industrial applications [2]-[5]. Atmospheric air gasification of biomass and waste in a bubbling fluidized bed reactor is an attractive, simple process to convert a solid material to a gaseous fuel [6]. This process leads to a fuel gas suitable for co-firing in existing boilers and with proper gas cleaning it may be used as an alternate fuel for gas engines and gas turbines for generating electricity [7].

The quality of the gas produced (composition, production of CO, H_2, CO_2 and CH_4 and energy content) and the gasification performance (gas yield) depend upon feedstock origin, gasifier design and operating parameters such as temperature, static bed height, fluidizing velocity, equivalence ratio, gasifying agent which are explain elsewhere [7]-[11]. Warnacke demonstrated that the gas composition is a function of gasifier design whereby the same fuel may give different calorific values with different gasifiers [10]. Among all designs, the fluidized bed gasifier has been shown to be a versatile technology capable of burning practically any waste combination with high efficiency. Fluidization is one of the most promising technologies due to a series of reasons. The great operating flexibility makes possible to utilize different fluidizing agents, reactor temperatures and gas residence times, to add reagents along the reactor freeboard or riser and to operate with or without a specific catalyst. Fluidized beds are used for a broad variety of fuels; this flexibility with respect to different fuels is actually another stronghold of fluidized beds. In terms of the utilized fuels, coal has been most often applied so far, but also waste and biomass have been utilized and are forecast to play a more important role in the future. Fluidized bed conversion of solid fuels into producer gas is also of significant economic importance nowadays; especially in developing countries. The development of fluidized bed gasifiers for small particle materials has made a great progress in biomass gasification. The productivity of the fluidized bed gasifiers was raised about 5 times as many as of the fixed bed gasifier and the heating value of the gas increased about 20%. Bed materials such as silica sand, calcined limestone, etc. are used in fluidized bed gasification systems for effective heat and mass transfer. A fluidized bed reactor operating under medium temperature (around 900-1,000 °C), is an alternative to agricultural waste gasification with air as gasifying agent [3].

In this work, a laboratory scale fluidized bed gasifier was developed to investigate the characteristics of gasification of biomass having specific size. The effect of gasification temperatures, fluidization velocity, static bed height and equivalence ratio (ER) on gas composition, gas yield and gas heating value were studied.

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II. Experimental Section

A. Experimental Set Up

Agricultural wastes (sawdust from a local saw mill and pigeon pea, *Cajanus cajan,* from farm) were selected for this study. The samples of pigeon pea were air dried for 2 to 3 days to remove moisture and to facilitate crushing. After crushing sizing of these materials was done by passing the materials through different sieves. Specific sizes of these materials were taken for this study was in the range of 0.40 to 0.84 mm. The proximate analyse and cold flow fluidization properties of the both biomass and bed material (sand) were reported in Tables I and II. The schematic diagram of the experimental facility used in this study is shown in Fig. 1. The gasifier was specially designed for operation under atmospheric or pressurized conditions. The fluidized bed gasifier, having an internal diameter of 210 mm and height of 1600 mm, was made of heat resistant stainless steel and surrounded by individually controlled ceramic bend heater (located at the bed section) to supply heat for startup. The gasifier reactor was surrounded by glass wool to counter the heat loss from the reactor. Six K-type thermocouples (T_1, T_b, T_2, T_3, T_4, and T_5) were installed across the reactor: the probe T_1 installed below the distributor plate for measuring the temperature of inlet air to the reactor. Two K-type thermocouples (T_b and T_2) were installed at the bed section of the reactor. The probe T_b installed at bed section (at the height of 150 mm above the distributor plate) measures the temperature of static bed and probe T_2 installed at bed section (at the height of 400 mm above the distributor plate) measures the temperature of fluidized bed. Another two K-type thermocouples (T_3 and T_4) were installed at the freeboard section of the reactor. The probe T_3 installed at bed section (at the height of 1000 mm above the distributor plate) measures the temperature of pyrolised gas and probe T_4 installed at bed section (at the height of 1300 mm above the distributor plate) measures the temperature of producer gas in the section. The remaining K-type thermocouple (T_5) was installed at the gas outlet pipe after the cyclone saperator. The samples were delivered into the dense bed zone of the gasifier using a calibrated feeder. Prior to gasification tests, both the fuel samples were taken in the range 0.4-0.84 mm in order to ensure the homogeneity on the biomass composition. Air was supplied by a regenerative blower at an atmospheric temperature via a multi-orifice plate distributor. Flow rate of air was measured by digital flow meter installed at downstream of the regenerative blower. Sampling gas bags were employed to collect the product gas just leaving the cyclone separator for gas composition analysis using on line producer gas analyser.

TABLE I
Proximate Analysis of the Feed Materials

Material	Moisture content	Ash content	Volatile matter	Fixed Carbone
Saw Dust	7.4336	4.8179	78.4249	9.3237
Pigeon Pea	7.8363	4.5508	78.6119	9.0010

TABLE II
Fluidization Properties of the Feed Materials and Bed Material

Material	Particle size (mm)	Fluidization Regime	Minimum fluidization velocity (m/s)	Maximum air velocity (m/s)
Sand	0.4-0.595	Bubbling	0.4	0.6
Saw dust	0.4-0.841	Bubbling	0.26	0.6
Pigeon pea	0.4-0.841	Bubbling	0.28	0.6

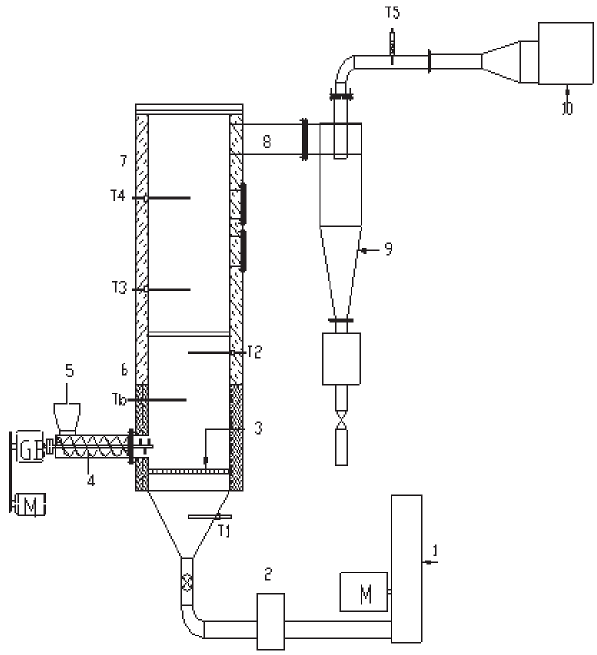

Fig. 1 Schematic diagram of the fluidized bed gasification system: 1: Regenerative Blower, 2: Digital Flow Meter, 3: Distributor Plate, 4: Screw Feeder, 5: Feed Hoper, 6: Bed Section, 7: Free Board Section, 8: Gas Outlet, 9: Cyclone Separator, 10: Burner

B. Experimental Procedures

Experiments were conducted on fluidized bed gasifier with sawdust and pigeon pea as feed material. Ceramic band heater is switched on which cuts off at 550 ^{0}C maintaining constant temperature. After temperature is reached air is blown from bottom until the bed temperature is uniform. Then biomass is fed at required feed rate and air flow rate is regulated as per predetermine equivalence ratio. After 5 to 10 minutes the bed temperature increases up to 700 to 900 ^{0}C due to gasification of biomass. The producer gas produced in this process passes through the fluidized bed section, cyclone separator and burner. Experiments were conducted on fluidized bed gasifier with sawdust having size in between 0.4 to 0.84 mm as a feed material and sand with size 0.4 to 0.595 mm as a bed material. Air is used as fluidizing agent. The experiments were conducted with six different equivalence ratio as indicated in Table III. Temperatures at six different locations along the length of gasifier were recorded. The sample of producer gas was collected in balloon after cyclone separator for gas composition. Same set of experiments also repeated for pigeon pea as feed material with same particle size as above sawdust. In these experiments sand was used as bed material and air was used as fluidizing agent. These experiments were conducted for five different equivalence ratio as indicated in Table III.

TABLE III
TEMPERATURE PROFILE THROUGH THE GASIFIER REACTOR

Material	ER	T1	T2	T3	T4	T5	Tb
Sawdust	0.35	44.5	453.5	330.5	309.5	139.5	647.5
	0.41	46.67	689.67	534	519	262.67	689.67
	0.44	45	512	313.5	289.5	112.5	1053.5
	0.49	46.33	493.67	343	320.67	138.71	717.78
	0.52	47.67	544	475.33	472.33	213.67	726
	0.61	31.67	535	477	483.67	185.33	683
Pigeon Pea	0.38	43	650	485	460	196.67	963.33
	0.48	43.67	594	424.33	426.67	180	842.67
	0.52	46.4	605	303.6	275.6	98.2	1094.8
	0.58	44.67	548.33	446.33	443.67	203.67	777.67
	0.68	44.67	566.67	451.67	442.67	172	780.67

III. RESULTS AND DISCUSSION

Experiments were conducted on 50 kg fuel/hr (variable capacity) bubbling fluidized bed gasifier with sized biomass to check the effect of equivalence ratio on gas calorific value, Temperature profile through reactor and efficiency of the gasifier. Effect of sized biomass on temperature profile, gas calorific value and gasifier efficiency is discussed in following section.

A. Gasifier Temperature Profile

The average temperatures recorded at the inlet (T_1), dense bed (T_b, T_2), freeboard (T_3, T_4), and gas outlet (T_5) are given in Table III. Figs. 2 and 3 show the gasifier temperature profiles in the dense bed, free- board and the exit of the gasifier at different equivalence ratios for feed material sawdust and pigeon pea. The lowest temperature readings were recorded below the distributor plate (T_1) and ranged from 32 to 48 ^{0}C. This was due to the cooling effect of the incoming air. The temperatures recorded in the bed section T_b and T_2 ranged from 650 ^{0}C to 1100 ^{0}C and 450 to 700 ^{0}C, respectively. This was due to the dense bed which had a much higher temperature. The temperature readings obtained from the two probes in the dense bed (T_b and T_2) showed that the temperature distribution within the bed was very uniform as compared with a downdraft gasifier, in which the temperature can swing by as much as 300 to 400 ^{0}C [12]. This stability attested to good particle distribution within the bed. The large heat exchange generated by the rapidly moving solid particles and does away with the harmful hot spots occurring in downdraft or updraft gasifiers. These are very much within the range of 627 to 927 ^{0}C reported in the literature [13], [14] for desirable operation of a fluidized bed gasifier. The behavior of the freeboard temperature is 150 to 200 ^{0}C relatively lower than the bed section temperature (T_2). The increase in gasifier temperatures with increasing equivalence ratio can be explained by the fact that at higher equivalence ratios more air (or oxygen) per unit weight of fuel was available for the exothermic carbon combustion that released heat and thus, gives rise to the gasifier temperature.

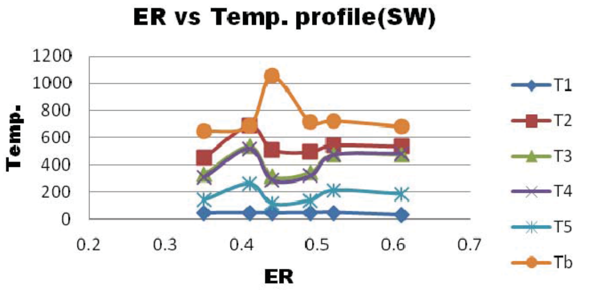

Fig. 2 Temperature profile in FBG with feed material sawdust

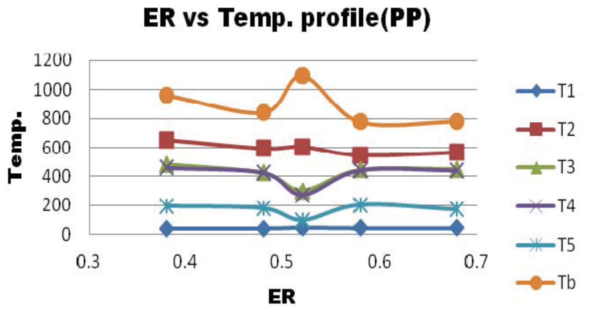

Fig. 3 Temperature profile in FBG with feed material pigeon pea

B. Producer Gas Composition

The various components of the gas produced at various equivalence ratios are summarized in Table IV. The results revealed that the concentration of major readings of CO_2 was in the range of 9-13.5 vol %. From the fuel gases which are of major interest, CO had the highest concentration (7.47-13.02 vol %), followed by H_2 (1.63-12.87 vol %), and then CH_4 (3.54-8.08 vol %). The other components (O_2, C_2H_2+C_2H_4 and C_2H_6) were produced with lower concentrations. Generally, as the equivalence ratio was increased, the concentrations of CO_2 and N_2 increased while the concentration of the fuel (combustible) gases (CO, H_2CH_4, C_2H_2+C_2H_4 and C_2H_6) decreased. For sawdust material maximum amount of CO (13.02 vol %) and maximum amount of H_2 (12.87 vol %) was obtained at the equivalence ratio (0.41). For pigeon pea material maximum amount of CO (11.44 vol %) and maximum amount of H_2 (12.44 vol %) was obtained at the equivalence ratio (0.52). As stated by [15], ER not only represents the oxygen quantity introduced to the reactor but also affects the gasification temperature under the condition of auto thermal operation. While on the other hand, higher ER means higher gasification temperature, which can accelerate the gasification and improve the product purity to a certain limit. Therefore, the gas composition is affected by the two contradictory factors of ER. Also, [4] suggested that this increase in CO and H_2 is due to thermal cracking of hydrocarbons and tars at a higher temperature. While the decrease in CO and H_2 with further increase in ER due to partial combustion of different gaseous components resulted in further increase in CO_2 concentration.

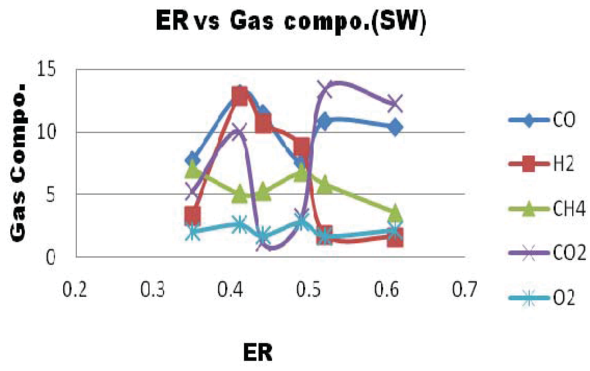

Fig. 4 Producer gas composition in FBG with feed material sawdust

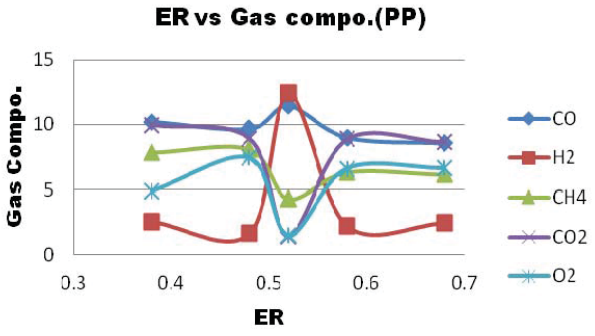

Fig. 5 Producer gas composition in FBG with feed material pigeon pea

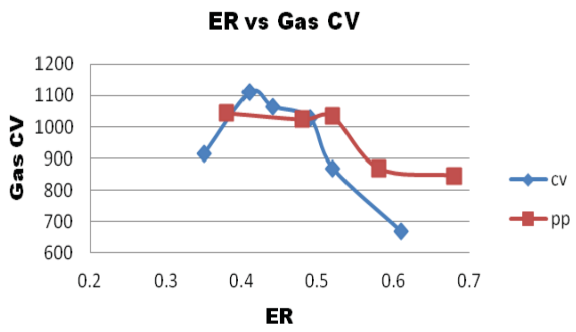

Fig. 6 Gas calorific value in FBG with both feed materials

TABLE IV
PRODUCER GAS COMPOSITION AND GAS CV OF BOTH FEED MATERIAL AT DIFFERENT EQUIVALENCE RATIO

Material	ER	CV	CO	H_2	CH_4	CO_2	O_2
Sawdust	0.35	915	7.65	3.27	7.05	5.24	2.04
	0.41	1110	13.02	12.87	5.05	10.02	2.6
	0.44	1066	11.47	10.71	5.2	1.17	1.71
	0.49	1027	7.47	8.78	6.73	3.16	2.79
	0.52	870	10.84	1.8	5.8	13.44	1.7
	0.61	668	10.44	1.61	3.54	12.25	2.17
Pigeon Pea	0.38	1044	10.22	2.56	7.83	9.97	4.88
	0.48	1024	9.68	1.63	8.08	8.93	7.41
	0.52	1033	11.44	12.44	4.28	1.4	1.49
	0.58	869	9.01	2.24	6.31	8.86	6.6
	0.68	846	8.58	2.45	6.13	8.63	6.62

C. Gas Higher Heating Value

The results of the gas higher heating value are given in Table II and presented in Fig. 6. The higher heating value of the product gas for sawdust was reported in the range of 668 to1110 kcal/m^3 while same for pigeon pea was in the range of 846 to 1044 kcal/m^3. The results revealed a pronounced effect of the equivalence ratio on the higher heating value of the gas. Increasing the equivalence ratio resulted in a decrease in the higher heating value of the gas due to decreases in the concentrations of methane which has relatively large heating values. For sawdust maximum amount of higher heating value was 1110 kcal/m^3 at equivalence ratio 0.41 and for pigeon pea maximum amount of higher heating value was 1044 kcal/m^3 at equivalence ratio 0.38.

IV. CONCLUSIONS

In present time whole world facing energy crises. Fossil fuel reserves are depleting at faster rate. For sustainable development renewable energy sources are the only and premising solution. Since India is agricultural country, ample biomass is available for energy supplement and gasification is established technique to trap the energy from biomass.

Now in present work experiments were carried out on fluidized bed gasifier with sawdust and pigeon pea material. Following are the measure conclusions.

- Most efficient equivalence ratio for both the biomass is 0.38 to 0.41 and fluidization velocity for selected sized biomass (i.e. 0.4-0.841 mm) is 0.4 m/s.
- For better gasification of biomass required temperature of the bed material during starting the gasifier is 550^{0}C while same during running stage is 700^{0}C. Freeboard temperature should be maintained at 475^{0}C to 550^{0}C. Gas temperature should be maintained at 200^{0}C to 250^{0}C. Thermal (Hot Gas) Efficiency of the system at best ER for sawdust is 73.5% and for pigeon pea is 70.5 %.

Gasification of sized biomass was successfully performed in a fluidized bed gasifier, producing a fuel gas with a higher heating value in the range of 668 to 1110 kcal/nM^3 and 846 to 1044 kcal/nM^3 for sawdust and pigeon pea, respectively, which could be used in many end use applications. Among the gasification parameters tested, the equivalence ratio appeared to have the most pronounced effect on the reactor temperature, the gas composition, the gas heating value. The selection of suitable equivalence ratio would depend on the final use of the gas produced. As a higher ER had complex effects on tests results and there existed an optimal value for this factor, which was different according to different operating parameters. The influence of equivalence ratio on the performance of a gasifer could be regarded as the effect of reactor temperature as the reactor was found to be ER dependent.

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