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Experimental Study on Effects of Addition of Rice Husk on Coal Gasification

M. Bharath, Vasudevan Raghavan, B. V. S. S. S. Prasad, S. R. Chakravarthy

***Abstract*—In this experimental study, effects of addition of rice husk on coal gasification in a bubbling fluidized bed gasifier, operating at atmospheric pressure with air as gasifying agent, are reported. Rice husks comprising of 6.5% and 13% by mass are added to coal. Results show that, when rice husk is added the methane yield increases from volumetric percentage of 0.56% (with no rice husk) to 2.77% (with 13% rice husk). CO and H_2 remain almost unchanged and CO_2 decreases with addition of rice husk. The calorific value of the synthetic gas is around 2.73 MJ/Nm^3. All performance indices, such as cold gas efficiency and carbon conversion, increase with addition of rice husk.

***Keywords*—**Bubbling fluidized bed reactor, coal gasification, calorific value, rice husk.

I. Introduction

DECREASING trend in the availability of fossil fuels and an increase in the concern on pollution and climate change have created an interest on addition of bio-fuels for conversion of fossil fuels into useable energy. Solid fuels are complex to handle and gasification is found to be a viable technology for thermo-chemical conversion of coal and biomass to energy and for the production of valuable products. A reduction of green- house gas when biomass is added to coal is evident given the renewable character of biomass and the higher efficiency that gasification has when compared to combustion.

India has largest coal reserves and coal is the principle source of energy [1]. At the same time, residual biomass, specifically rice husk is abundant given extensive production of rice [2]. The study of effects of addition of rice husk on coal gasification case seems, therefore, to be relevant.

Among all gasification technologies, fluidized beds are often chosen because of their operating flexibility [3]. Co-gasification is a relatively new technology even though literature covers studies on effect of co-feeding different fuels into fluidized bed gasifiers [2].

Synergy between the products and the intermediates produced during gasification of different materials could lead to improvement in performance, reduction in carbon losses and increase in energy content of the resultant gas [4].

Synergistic effects arise due to interaction between evolved volatiles or between the volatiles and char/ash in the fuel [5]-[7]. This work presents results on the effects of rice husk addition on coal gasification in a lab-scale fluidized bed gasifier operating at atmospheric pressure with air as gasifying agent. In the experiments, air/fuel ratio is varied from 1.72 to 1.6 kg/kg with a goal of determining the effect that rice husk makes with respect to gasification performance. The coal and rice husk mixtures have been successfully gasified.

M. Bharath, M. S. Student, B. V. S. S. S. Prasad, Professor, Mechanical Engineering Department, Indian Institute of Technology Madras, Chennai, India 600036 (e-mail: bharaths094@gmail.com, Prasad@iitm.ac.in).
Vasudevan Raghavan, Associate Professor, Mechanical Engineering Department, Indian Institute of Technology Madras, Chennai, India 600036 (corresponding author, phone: +91-44-22574712; e-mail: raghavan@iitm.ac.in).
S. R. Chakravarthy, Professor, Aerospace Engineering Department, Indian Institute of Technology Madras, Chennai, India 600036 (e-mail: src@ae.iitm.ac.in).

II. Design Procedure

The thermal power rating of bubbling fluidized bed gasification reactor has been fixed as 40 kW based on the available dimension of the reactor, choice of regime and particle size ranges of coal and rice husk. The equivalence ratio has been fixed as 0.3 for coal and 0.22 for rice husk based on trial experiments. The results from proximate and ultimate analysis of Indian coal and rice husk used in this work are reported in Table I. The higher calorific value of a solid fuel in kJ/kg, is calculated by using Dulong and Petit equation, given as

$$HHV=33823\times C+144249\left(H-\frac{O}{8}\right)+9418\times S$$

where C, H, O and S are the mass percentages of carbon, hydrogen, oxygen and Sulphur, respectively, and are obtained from the ultimate analysis given in Table I. Higher heating value of coal is 17.76 MJ/kg and that of rice husk is 13.29 MJ/kg.

The fuel feed rate has been calculated for 40-kWth power output. The addition of rice husk of 6.5% and 13% is on weight basis. Air flow rate is calculated as per the equivalence ratios of both fuels. The hydrodynamic calculations are carried out to establish the particle sizes and operating conditions of the gasification device [8], [9]. The minimum fluidization velocity (U_{mf}), superficial velocity (U_o), transport disengaging height (TDH) and total height have been calculated for different cases for a range of average particle sizes [8], [9] at the experimental operating conditions of pressure at 1 atmosphere and an average temperature of 850 °C.

III. Experimental Setup

Fig. 1 presents a schematic diagram of the fluidized bed gasifier and its auxiliary equipment. The reactor has an internal diameter of 0.15 m and a height of 2.5 m and is lined with two 100 mm layers of refractory cement. The distributor plate is conical in shape and has 240 holes of 2 mm diameter drilled perpendicular to its surface. It is located at the top of wind box. Temperature along the reactor is measured using K-type thermocouples placed at different locations from the top surface of the distributor plate. The solid feed rate is measured using a screw feeder calibrated for different mixtures of coal and rice husk. It is located at 0.5 m above the distributor plate. A stream of air is pre-heated before supplied to the wind box.

IV. Fuel

Coal and rice husk particles require size reduction before they are fed into the gasifier. The raw coal is crushed is screened to obtain required particle size range. Similarly, rice husk is also screened to obtain required particle size range. Sand is mixed with rice husk in the ratio of 1:1.5 to ensure that it flows without getting jammed in the feeder. The rice husk contributes to 6.5% - 13% by weight in the fuel mixture.

Rice husk is a complicated mixture of complex compounds such as cellulose, hemicellulose, and silica, alkali elements (Na, K, Mg, and Ca) rice husk produces char, condensable volatiles and tar, and gaseous products during devolatilization [11]. Char is mainly of carbon, and it follows reactions 1 to 7 during gasification. All of the volatiles and some tars are thermally cracked and broken down into small gaseous products during gasification. The remaining tar and some alkali minerals leave with product gases.

V. Gas Analysis

The product gas enters a filter, which is fitted with 0.25 mm size mesh and a water scrubber, to filter the fly ash. A certain quantity of gas is extracted in regular intervals and fed into the gas analyzer (Fig. 1) to measure the volumetric percentages of components present. The gas analyzer has been pre-calibrated, the sensors used for measuring CO, CO_2, and CH_4 are of non-dispersion infrared type [1]. For O_2, electrochemical type sensor is used and for H_2, thermal conductivity based sensor is used. The estimated errors of the gas analysis measurements are ±0.1 %. The gas analyzer is purged with atmospheric air at regular intervals.

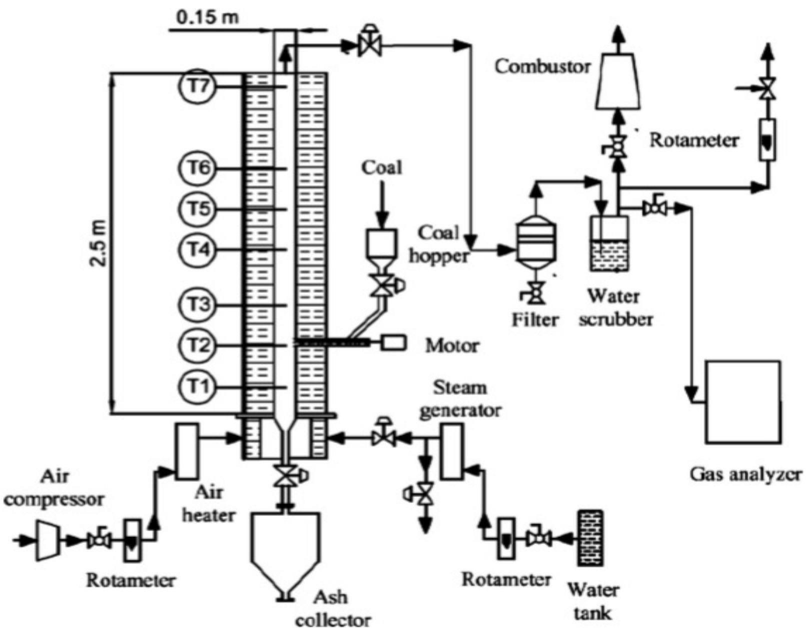

Fig. 1 Schematic of bubbling fluidized bed gasifier

TABLE I
Solids Characterization

Fuel	Proximate analysis (% wt., air dried)				Ultimate analysis (% wt., air dried)				
	Ash	M	VM	FC	C	H	N	O	S
Coal	36.4	5.4	28.7	29.5	43.7	3.8	0.9	14.5	0.7
Rice husk	21.9	7.12	55.85	15.24	35	5.5	0.32	36	0.08

VI. Experimental Procedure

Pulverized coal particles and rice husk are ground, sieved using standard sieves; the maximum and minimum sizes of the sieve are reported as the range of particle size. To achieve ignition and to pre-heat the bed, the reactor is filled with 2.5 kg of bed material (sand particles of size 0.8 mm - 1 mm) and 3 kg of coal particles (0.8 mm - 1 mm). Air at a required rate is preheated to 350 °C and supplied through the wind box to achieve proper fluidization of solid particles. To heat up the refractory and the initial solids in the reactor, Liquid Petroleum Gas (LPG) is supplied from a port located 0.2 m above the distributor plate. Using a pilot flame, the mixture of LPG and air has been ignited. When the temperature of the dense bed reaches to around 600 °C, LPG supply is cut-off. The combustion of coal particles continues to increase the bed temperature. When the bed temperature reaches around 1000 °C, coal or coal + rice husk particles are fed using the screw conveyor. At the time of feeding, the bed temperature momentarily decreases as the fresh material is being fed. The rate of solid fuel feeding has been gradually increased to the required value. Steady state operation is reached within around one hour.

During the steady state operation, removal of bed material and ash from the reactor is carefully carried out in regular intervals. The weight of ash removed is also measured using a load cell. Temperatures at several locations are recorded continuously. The synthetic gas is analyzed using a gas analyzer connected to a desktop computer, where the data are recorded as a function of time. The flow rate of synthetic gas leaving the scrubber is measured using pre-calibrated rotameter. The synthetic gas is subsequently burnt in a combustor. The reactor is operated for around 4 to 5 hours such that steady state operation lasts for at least 3 to 4 hours for each case. All the cases have been repeated at least three times to ensure similar operating conditions and output. It has been observed that the data have been repeatable within 2% around the average values.

To calculate the amount of unburned carbon present in the samples, metrics such as total carbon conversion and fixed carbon conversion have been calculated using the procedure reported by Engelbrecht et al. [10].

The formulae for calculating the fixed carbon conversion and total carbon conversion are given as,

$$\text{Fixed carbon conversion} = \frac{\{(a \times b)-[(d \times e)+(f \times g)]\}}{(a \times b)},$$

$$\text{Total carbon conversion} = \frac{\{(a \times c)-[(d \times e)+(f \times g)]\}}{(a \times c)},$$

where ‘a’ is fuel feed rate in kg/h, ‘b’ is the percentage of fixed carbon content in fuel, ‘c’ is the percentage of carbon content in fuel, ‘d’ is the flow rate of bed ash in kg/h, ‘e’ is the percentage of carbon content in bed ash, ‘f’ is the flow rate of filter ash in kg/h and ‘g’ is the percentage of carbon content in filter ash. Cold gas efficiency is calculated using the formulae [10] given as:

$$\text{Cold gas efficiency} = \frac{\text{Syngas flow rate in m}^3\text{/s x Gas HHV in MJ/m}^3}{\text{Fuel feed rate in kg/s x Fuel HHV in MJ/kg}} \times 100,$$

Gas higher heating value (HHV) depends on product volume percentages (V_i) of CH_4, CO and H_2 and their calorific values (CV_i). It is calculated as,

$$\text{Gas HHV} = \frac{V_{CH_4} \times CV_{CH_4} + V_{CO} \times CV_{CO} + V_{H_2} \times CV_{H_2}}{100}$$

VII. Results and Discussion

It is well known that the gasification process of biomass (rice husk) and coal occurs through three steps. The first is devolatilization or pyrolysis step, which occurs at lower temperatures, and produces volatile matter and char residue. The secondary reactions start to take place involving the volatile products. This is the second step. Third, the gasification reactions of the remaining carbonaceous residue occur with carbon dioxide and steam. Volatiles and char participate in reactions (1)-(7) as summarized below [8], [9].

$$\text{Oxidation reaction: } C+O_2 \Leftrightarrow CO_2 \quad (1)$$

$$\text{Partial oxidation reaction: } C+0.5O_2 \Leftrightarrow CO \quad (2)$$

$$\text{Boudouard reaction: } C+CO_2 \Leftrightarrow 2CO \quad (3)$$

$$\text{Water gas reaction: } C+H_2O \Leftrightarrow CO + H_2 \quad (4)$$

$$\text{Methane formation reaction: } C+2H_2 \Leftrightarrow CH_4 \quad (5)$$

$$\text{Water gas shift reaction: } CO+H_2O \Leftrightarrow CO_2 + H_2 \quad (6)$$

$$\text{Steam methane reforming reaction: } CH_4+H_2O \Leftrightarrow CO+3H_2 \quad (7)$$

Table II reports the input and output parameters for experiments carried out with coal and coal + rice husk (added to contribute to 6.5% and 13% on weight basis). The parameters include solid fuel flow rates, product gas composition, carbon conversion, cold gas efficiency, calorific value of syngas, and air to solid fuel ratio. All runs are carried out for a total power output of 40 kW_{th}.

Gasification temperature is important for achieving controlled operation. First three thermocouples are located at 0.3 m distance from each one starting from 0.2 m from the top surface of the distributor plate. The maximum temperature in the reactor is attained in the predominant oxidation zone. This is controlled by monitoring the first three thermocouples and feeding air and/or removing ash, appropriately. This helps avoiding sintering of ash that occurs at a high temperature [10]. The variation of temperature along the height of the reactor for 6.5 wt.% and 13 wt.% cases with air as gasifying agent is shown in Fig. 2.

The average bed temperature from different trials, measured from the first thermocouple under steady state conditions, varies in the range of 926 °C to 911 °C, as the rice husk percentage by mass of 6.5% and 13% is added. The maximum temperature reported is 935 °C for 15% rice husk by mass and 910 °C for 6% by mass [3]. It should be noted that higher temperature may prevail below 0.2 m. However, ash-melting and sintering problems have not been encountered in all the three trials. The temperatures at locations of 0.2 m and 0.5 m do not vary significantly. At higher locations, temperature decreases.

Fig. 3 shows the volumetric percentages of CO, CO_2, H_2 and CH_4 present in the product gas for different cases. In all the three trials, oxygen has been slightly in excess and a maximum volume percentage of 0.3 to 0.4 is obtained at the exit, which is not reported in Table II or Fig. 3. With an increase in the rice husk content, methane yield increases from volumetric percentage of 0.56% (with no rice husk) to 2.77% (with 13% rice husk). CO and H_2 remain almost unchanged and CO_2 decreases with addition of rice husk. The variation trend of CH_4 significantly increases the cold gas efficiency.

TABLE II
SUMMARY OF EXPERIMENTAL INPUT AND OUTPUT PARAMETERS

Case number	1	2	3
Power (kW_{th})	40	40	40
Percent rice husk (by weight)	0	6.5	13
Coal flow rate (kg/h)	8.1	7.7	7.3
Rice husk flow rate (kg/h)	0	0.53	1.0
Total air flow rate (kg/h)	13.92	13.74	13.5
ER- Coal	0.3	0.3	0.3
ER- Rice husk	-	0.22	0.22
Air to fuel ratio	1.72	1.72	1.62
Air temperature (°C)	335	335	335
Fuel particle size (mm)			
Coal	0.8-1	0.8-1	0.8-1
Rice husk	-	2-2.5	2-2.5
Dry gas composition (Volume %)			
CO	10.15	9.7	9.71
H_2	5.94	6	6.25
CH_4	0.56	1.5	2.77
CO_2	9.35	8.6	8.715
N_2 + Other	73.75	73.7	72.7
Gas calorific value (MJ/Nm^3)	2.145	2.45	2.73
Unburned carbon in fly ash (%)	15.5	13.5	13
Unburned carbon in bottom ash (%)	12.5	12.5	11.5
Fixed carbon conversion (%)	57.7	61.25	63.5
Total carbon conversion (%)	71.38	73.78	76.25
Cold gas efficiency (%)	69.4	70.5	71

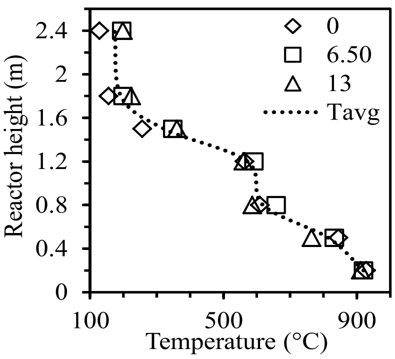

Fig. 2 Temperature profile along the height of reactor

Velez et al. [3] used 6% and 15% rice husk with coal by mass. They obtained synthetic gas having 6% and 5% CO, respectively, for these cases. They have used steam/fuel ratio of 0.7 for 6% case and 0.73 for 15% case which gave a higher hydrogen yield of 11.4% and 14%, respectively. In this present case rice husk contributing to 6.5% by mass, volume percentages of CO and H_2 are 9.7 and 6, respectively and rice husk contributing to 13% by mass, volume percentages of CO and H_2 are 9.71 and 6.25, respectively. These differences are due to changes in calorific value of coal and rice husk and dimensions of the reactor and operational conditions.

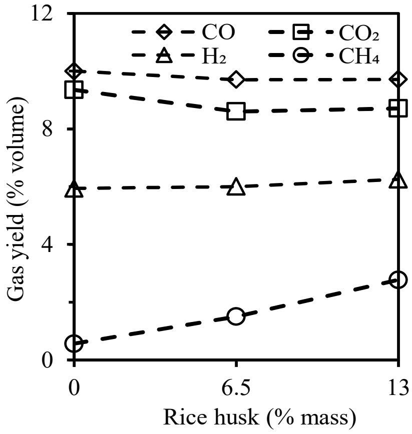

Fig. 3 Gas yield for three cases

Due to increasing trend of CH_4 with addition of rice husk content, the synthetic gas heating value also increases in the range of 0% to 13% of rice husk by mass, as shown in Fig. 4.

Velez et al. [3] reported SGHV of 1.6 MJ/m^3 and 4.4 MJ/m^3, respectively for 6% and 15% addition of rice husk by mass. Their Colombian coal had a low ash content of 15.4 % on dry basis and has a higher heating value of 20.58 MJ/kg as compared to that of Indian coal (17.76 MJ/kg). The ash content of Indian coal is around 36.4% on dry basis.

Cold gas efficiency is nearly 69.5% when only coal is gasified with air as gasifying agent as shown in Fig. 5. This value shows an increasing trend with the addition of rice husk. When rice husk contributes to 13% by mass, the cold gas efficiency increases to around 71%. This is due to notable increase in the carbon conversion (Fig. 6) and in the SGHV (Fig. 4). However, it may be observed that there is no significant variation in cold gas efficiency with the addition of rice husk from 6.5% by mass to 13% by mass.

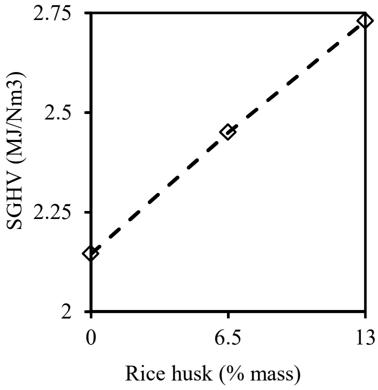

Fig. 4 Synthetic gas heating value for different blends

The cold gas efficiencies reported by Velez et al. [3] for 6% and 15% blends are 57% and 61%, respectively, as against 71% in the present case for 13% by mass contribution by rice husk. The air/fuel ratio has significance in the cold gas efficiency. Velez et al. [3] have used ratios of 1.89 and 1.84, respectively for their two cases and in the present case air-fuel ratios are 1.72 and 1.62, respectively. The effect of adding 6.5% by mass and 13% by mass of rice husk to coal shows an increasing trend in the carbon conversion percentage as shown in Fig. 6.

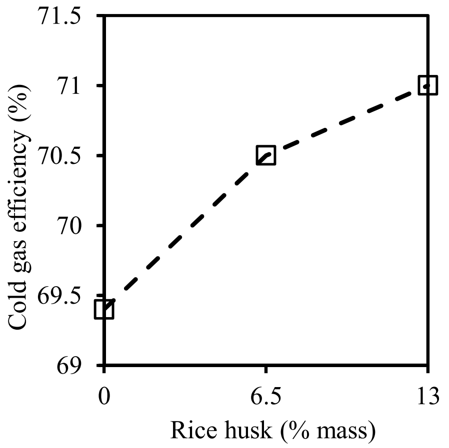

Fig. 5 Cold gas efficiency for different blends

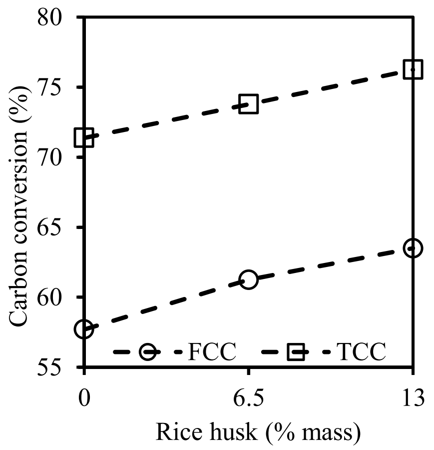

Fig. 6 Total and fixed carbon conversion

VIII. Conclusions

Experiments in a lab-scale fluidized-bed gasifier are reported and the effects of adding rice husk to coal contributing to 6.5% and 13% by mass are studied. Air is used as gasification agent. Reactor is operated at 40 kW_{th}, under atmospheric pressure. Results show that, when rice husk is added the methane yield increases from volumetric percentage of 0.56% (with no rice husk) to 2.77% (with 13% rice husk). CO and H_2 remain almost unchanged and CO_2 decreases with addition of rice husk. The calorific value of the synthetic gas is around 2.73 MJ/Nm^3. All performance indices, such as cold gas efficiency and carbon conversion, increase with addition of rice husk.

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References

[1] K. Vijay Kumar, M. Bharath, Vasudevan Raghavan, B. V. S. S. S. Prasad, S. R. Chakravarthy, T. Sundararajan, “Gasification of high-ash Indian coal in bubbling fluidized bed using air and steam - An experimental study,” Applied Thermal Engineering 116 (2017) 372–381.
[2] Lucio Zaccariello, Maria Laura Mastellone, Fluidized-Bed Gasification of Plastic Waste, Wood, and Their Blends with Coal, Energies. Italy (2015) 8052-8068.
[3] J. F. Vélez, F. Chejne, C. F. Valdés, E. J. Emery and C. A. Londoño, “Co-gasification of Colombian coal and biomass in fluidized bed: an experimental study,” *Fuel* 88 (3) (2009) 424–430.
[4] K. Sjöström, G. Chen, Q. Yu, C. Brage and C. Rosén, “Promoted reactivity of char in co-gasification of biomass and coal: synergies in the thermochemical process,” *Fuel* 78 (10) (1999) 1189–1194.
[5] M. H. Lapuerta, J. J. Hern´andez, A. Pazo, and J. L´opez, “Gasification and co-gasification of biomass wastes: effect of the biomass origin and the gasification reactor operating conditions,” Fuel Processing Technology 89 (9) (2008) 828–837.
[6] Y. G. Pan, E. Velo, X. Roca, J. J. Manya, and L. Puigjaner, “Fluidized-bed co-gasification of residual biomass/poor coal blends for fuel gas production,” Fuel 79 (11) (2000) 1317– 1326.
[7] J. J. Hernandez, G. Aranda-Almansa, and C. Serrano, “Cogasification of biomass wastes and coal-coke blends in an entrained flow gasification reactor: an experimental study,” Energy and Fuels 24 (4) (2010) 2479–2488.
[8] D. Kunii, O. Levenspiel, Fluidization Engineering, Butterworth-Heinemann, 1991.
[9] P. Basu, Combustion and Gasification in Fluidized Beds, Taylor and Francis Group, 2006.
[10] A. D. Engelbrecht, B. C. North, B. O. Oboirien, R. C. Everson, H. W. P. J. Neomagus, Fluidized bed gasification of high ash South African coals: an experimental and modelling study, Proc. Ind. Fluid. South Africa (2011) 145-160.
[11] Masnadi Mohammad S, Grace, John, T. Bi. Xiaotao, Lim Jim and Ellis Naoko, “From fossil fuels towards renewables,’’ Applied Energy (2015) 196-209.