Effect of equivalence ratio on gasification of granular biomaterials in self circulating fluidised bed gasifier

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Abstract: Biomass can be converted to gaseous fuels through thermo chemical conversion process. In this study rice husk, coir pith and saw dust were selected and gasified in a self circulating fluidised bed gasifier. Gas composition has been analysed for equivalence ratios of 0.3, 0.4 and 0.5 for 10-minute time intervals and its effect on gas constituents has been studied. The gas yield has been found to be in the range of 1.5–2.4 Nm^3/Kg, 1.6–2.9 Nm^3/Kg and 2–3.2 Nm^3/Kg for rice husk, coir pith and saw dust respectively. The study has been carried out in a pilot model gasifier.

Keywords: self circulating FBG; equivalence ratio; gas yield; reactor temperature; gas composition; pilot model.

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1 Introduction

Biomass can be converted into gaseous fuels called syngas or fuel gas through thermo chemical conversion process. Air, CO_2 steam and O_2 are commonly employed gasification agents. Physical dimension of gasifier, feed property and operating parameters are influencing the performance of gasifier to a larger extent. Sheeba et al. (2009) conducted experiments on coir pith gasification using air as gasifying agent. They observed that maximum yield of hydrogen 11.2% is obtained at a temperature of 1,028.6°C and discussed the effect of temperature on gas composition during gasification. Natarajan et al. (1998) reviewed combustion and gasification of rice husk in fluidised bed reactors on lab scale model and discussed the technical feasibility to gasify rice husk in fluidised bed reactor. Varshney et al. (2010) reviewed small scale biomass gasification technology in India and discussed MNRE supported biomass and bagasse based power plants in India with installed capacity. Gasification technology energy conversion from biomass was reviewed by Mckendry (2002) and concluded with viable process through biomass properties and pre-treatment. Saw dust gasification was carried out in a fixed bed, downdraft, and stratified gasifier by Wander et al. (2004) of 12 kg/h capacity. The effect of biomass/steam ratio, temperature and catalyst activity for increasing H_2 yield from gasification technologies was reviewed by Saxena et al. (2008). Biomass gasification in bubbling and atmospheric fluidised bed gasifier under the influence of gasifying agents using air, steam and steam-oxygen mixture were carried out by Gil et al. (1999) and concluded that the use of steam resulted in an increase in hydrogen yield. The present study is carried out in a self circulating fluidised bed gasifier which is characterised by higher gas velocity and better mixing in riser column. Self circulating fluidised bed gasifiers are more advantage over fixed bed gasifier for medium and large capacity plants and for better carbon conversion efficiency. From the literature study various research works have been carried out in fluidised bed gasifier using variety of fuels like bagasse, crop stalks, saw dust, and coir pith. This study was carried out for syngas generation through gasification from the biomass rice husk, coir pith and sawdust and its application in rural regions energy requirements.

2 Biomass and inert bed materials

Rice husk, coir pith and saw dust were collected from Samayapuram near Trichy, Tamilnadu where plenty of agricultural residues are available. Sand was used as the bed inert material and its particle size has been selected as 0.375 mm through sieve analysis. Henderson and Perry (1966) conducted sieve analysis to predict particle size distribution of biomass materials having a size up to 3 mm. Lin et al. (2002) conducted particle size distribution in a set of standard sieves. Proximate analysis, which is the percentage of moisture content, volatile matter, ash content and fixed carbon was determined and shown in Table 1.

Table 1 Proximate analysis

S. no.	*Proximate analysis*	*Rice husk*	*Coir pith*	*Saw dust*
1	% moisture content	6	4	13.5
2	% volatile matter	64.5	65	71
3	% ash content	16	12.5	11.5
4	% fixed carbon	13.5	18.5	4
5	Total	100	100	100

Lin et al. (2002) determined the minimum fluidisation velocity experimentally by pressure drop method using U tube manometer. Minimum fluidisation velocity for sand as inert material in FBC of rice husk was selected as 0.66 ms^{-1}. Similarly for coir pith and saw dust the minimum fluidisation velocity was fixed as 0.19 and 0.27 ms^{-1} respectively.

3 Experimental setup and procedure

3.1 System description

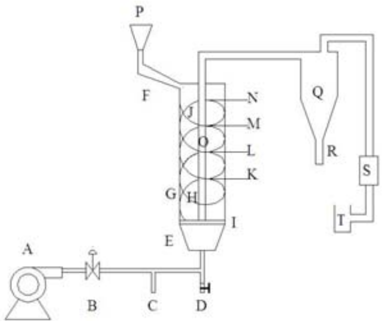
The experimental setup consists of a centrifugal blower, self circulating fluidised bed gasifier, air distributor plate, riser column, rotameter, pressure tapping, temperature tapping and cyclone separator. A control valve regulates the air from the blower to the gasification system. Flow rate of air is measured by pressure tapping which is connected to U tube manometer. The pressure tapping is also provided at different locations above and below the air distributor. Temperature tapping is provided at different location in the riser column. K type thermocouples are provided along the height of the gasifier to measure the temperature in gasifier. Proper insulation is provided between riser column and reaction outer chamber using fibre glass cloth in order to reduce heat loss. A rotameter with a capacity of 100 cc/min. is fixed at the end of the cyclone separator for measuring the flow rate of the producer gas.

The schematic diagram of experimental setup of a self circulating fluidised bed gasifier is shown in Figure 1.

3.2 Experimentation

The work is carried out in the Department of Mechanical Engineering in Star Lion College of Engineering and Technology group of institutions, Thanjavur. The photographic view of experimental set up is shown in Figure 2. Dimensions of the Gasifier are given in Table 2.

Figure 1 Fluidised bed gasifier-self circulating setup



Notes: A-blower, B-control valve, C-pressure tapping, D-rainvalve, E-pressure tapping lower end, F-pressure tapping upper end, G-reaction chamber, H-riser column, I-distributor plate, J-self circulating setup, K, L,M, N-temperature indicator, of luidising column, P-hopper, Q-cyclone seperator, R-dust collector, S-rotameter, T-burner.

Figure 2 Photographic view of experimental setup (see online version for colours)

Table 2 Dimension of Gasifier

Parts	*Description*	*Dimensions (mm)*
Riser column	Diameter	100
	Height	550
Outer chamber	Diameter	200
	Height	350
Cyclone separator	Height	400
Tangential inlet and circular exit	Inlet diameter	100
Distributor plate	Diameter	150

A systematic procedure is adopted for gasification of various biomasses in the self circulating fluidised bed gasifier. Biomass sample is first subjected to sieve analysis to remove unwanted materials present in rice husk, coir pith and saw dust in order to get the required size prior to experimentation. The biomass material is charged through the hopper which is kept at the top of the gasifier. The charged biomass reaches the bottom of the gasifier through a self circulating set up by gravity. Sand is used as inert material during gasification of biomass. 25% of sand is mixed with biomass depending upon the biomass used during gasification in fluidised bed. Initially the biomass is heated by dipping charcoal in kerosene and burnt inside the gasifier in order to sustain the temperature inside the system in order to attain stable temperature. The temperature is monitored by thermocouples located along the riser column.

Rice husk is mixed with sand and reaches the bottom of the reactor over the grate through the self circulating set up. Rice husk is pre heated when it passes through self circulating set up fixed around the riser column. Air is passed from the bottom of the grate through the distributor plate which takes the rice husk in the riser column. Synthesis gas along with sand and unburnt rice husk passes through riser column and reaches the cyclone separator. The gas is collected at the top of cyclone separator and the remaining solid particles reach the bottom of the cyclone which can be recirculated into the reaction chamber again. During this process temperature is monitored at different locations at regular intervals. The flow rate of producer gas is recorded by rotometer and gas composition is analysed by gas chromatography for every 10 min.

3.3 Data collection

The air flow rate is measured by making tapping in the pipe coming from blower which is connected to the U tube manometer. Four temperature probes (T1 to T4) are located at different heights along the riser column for measuring temperature of the Gasifier reactor. Gas flow rate is measured by using rotameter with a capacity of 100 cc/min. Gas constituents of producer gas are analysed by gas chromatography.

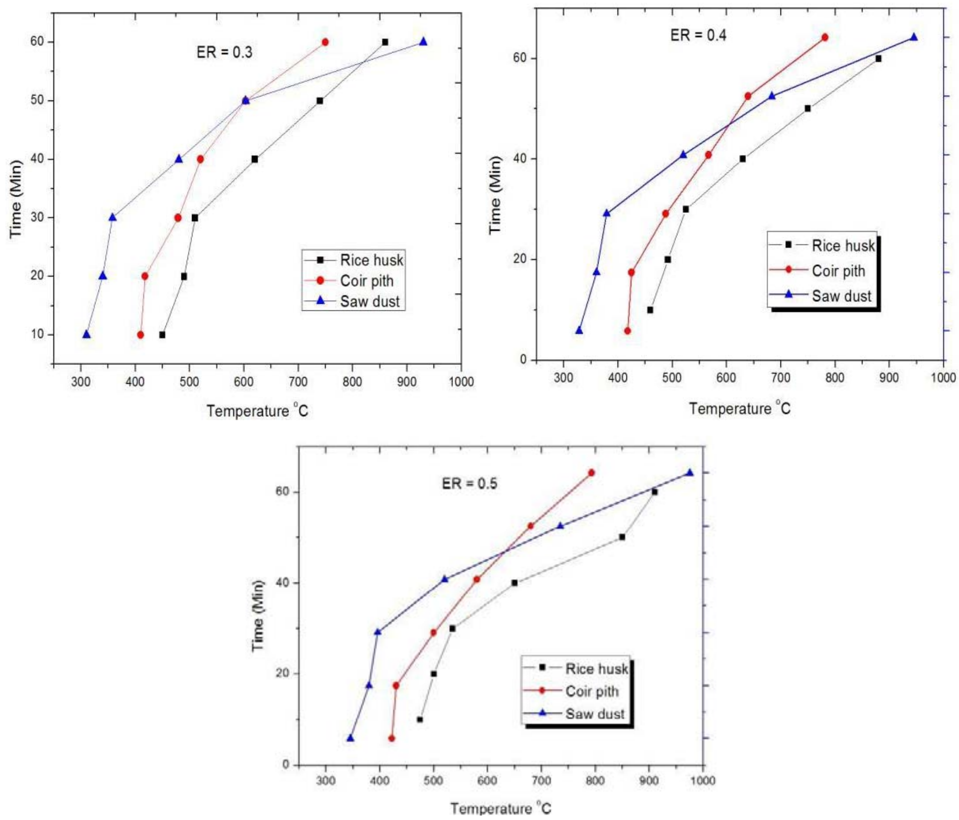
4 Results and discussion

In this study air is used as gasification agent. The effect of equivalence ratio (ER) on fluidised bed reactor temperature, gas composition and gas yield are studied and the results are given below.

4.1 Fluidised bed gasification and bed temperature

Initially the temperature of the reactor was increased gradually and it is done by heating the inert material along with burning the charcoal inside the reactor. The biomass material was fed into the reactor through hopper and air is allowed to pass through the distributor. The experiment was conducted for 1 hour run and the gas produced after passing the cyclone separator was measured and analysed for various ERs of 0.3, 0.4 and 0.5. Combustion is predominant beyond ER of 0.5 and pyrolysis below ER of 0.3. During gasification process the data were collected for every 10 min. The fluidised bed reactor temperature increases sharply and reaches the maximum value at the end of 60th min. of gasification. The maximum temperature attained for an ER of 0.3 during rice husk gasification was around 860°C. For an ER of 0.4 and 0.5 the temperature attained was around 880°C and 910°C. During coir pith gasification maximum temperature attained in the reactor was around 793°C. Similarly for saw dust the temperature increases with increase in ER and recorded at 975°C.With increase in ER, reaction temperature also increased due to more air supply. Mathieu and Dubuisson (1999) observed linear increase of reaction temperature with increase in ER. The effect of ER on reactor temperature for rice husk, coir pith and saw dust is shown in Figure 3.

Figure 3 Effect of ER on reactor temperature (see online version for colours)



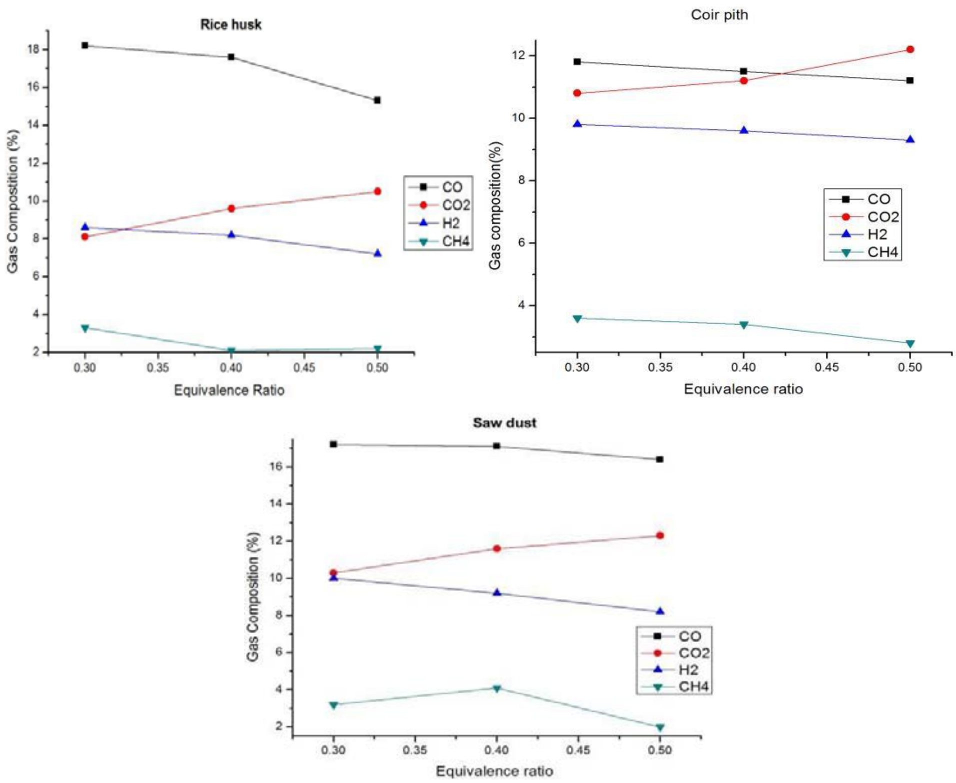
4.2 Gas composition

During gasification trial, the gas composition of synthesis gas such as carbon monoxide, carbon dioxide, methane and hydrogen were observed for every 10 min while the ER was varied from 0.3, 0.4 and 0.5. From the observed data carbon monoxide content increases with ER. Carbon monoxide value was in the range of 15.3–18.2% for rice husk. For coir pith and saw dust the range was 11.8 – 12.4% and 16.4–17.2% respectively.

Data on carbon dioxide revealed that increase in ER during gasification increases the percentage of carbon dioxide content in the synthesis gas. A maximum value of 10.5%

was observed at an ER of 0.5 and a minimum value of 8.1% at ER of 0.3 during rice husk gasification. The value of carbon dioxide content for coir pith and saw dust gasification revealed that the maximum value attained at ER of 0.5 with a value of 12.2% and 12.3% respectively. The results are compared with Mansaray et al. (1999) findings and are close to the experimental value. During fluidised bed gasification of biomass it was observed that the percentage of carbon monoxide decreases with increase in ER and the carbon dioxide content increases with increase in ER .The same trend was noticed by Hanb et al. (2008) and this reduction in level of carbon monoxide was due to high air flow rate.

Figure 4 Influence of ER on gas composition (see online version for colours)



The level of hydrogen generation during gasification of all biomasses showed a decreasing trend for higher ER. The quantity of hydrogen gas generated dropped from 8.6% to 7.2% during rice husk gasification. For coir pith and saw dust the results showed a drop in the hydrogen level of 9.8–9.3% and 10–8.2%.The same trend was observed by Subramanian et al. (2011) with a decrease in CO and hydrogen for higher ER in fluidised bed biomass gasification.

During biomass gasification in the self circulating fluidised bed gasifier the methane level generation was found to be low and the range of methane content was 2–3.6% for all the biomasses during the trial. The influence of ER on gas composition is shown in Figure 4.

4.3 Gas yield

From the gas flow rate and gas composition of synthesis gas the gas yield was calculated. The result showed that during gasification with increase in ER the gas production rate also increased for rice husk, coir pith and saw dust. The gas yield was found to be in the range of 1.5 to 2.4 Nm^3/Kg during rice husk gasification, for coir pith the gas yield was found to be in the range of 1.6 to 2.9 Nm^3/kg and for saw dust the gas yield was in the range of 2 to 3.2 Nm^3/kg.The present data was compared with the result obtained by Li et al. (2004) in a circulating fluidised bed gasification and the gas yield was in the range of 1.72–3.3 Nm^3/kg, which indicates that the present study is in good agreement with literature. The gas heating value was analysed form gas composition and it was found to be in the range of 1.8–4.1 MJ/Nm^3 for coir pith. Higher heating value in rice husk gas composition was found to be in the range of 2–4.2 MJ/Nm^3. The heating value of saw dust generated synthesis gas was in the range of 2.4–4.4 MJ/Nm^3 due to high carbon content and less ash content. Mathematical gas yield has been calculated for rice husk, coirpith and saw dust and the results showed a good agreement with the experimental data. For rice husk the mathematical gas yield was found to be in the range of 1.34–2.2 Nm^3/Kg. Coir pith has a range of 1.51–2.63 Nm^3/Kg gas yield, and for sawdust the gas yield range was 2.45–3.95 Nm^3/Kg.

5 Conclusions

Rice husk, coir pith and sawdust are gasified in the self circulating fluidised bed gasifier using air as the gasifying agent. Effect of ER on reactor temperature and gas composition and gas yield are studied. During biomass gasification, it is found that increase in ER favoured the linear increase in temperature for all the biomasses. The highest temperature attained was around 975°C at an ER of 0.5 for saw dust. The highest hydrogen composition obtained in this study was 10% for saw dust at ER of 0.5. It is observed that the gas heating value increases with ER and reaches a maximum value of 4.4 MJ/Nm^3 for saw dust comparatively higher than other biomasses at an ER of 0.5. The self circulating fluidised bed gasifier is useful for thermal application and power generation in small scale industries.

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