Experimental study and characterization of coal gasification in a circulating fluidized bed gasifier

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Abstract. In this study Indian coal material were used for the experiments and presents the results from gasification of Indian sub-bituminous coal in a (4.0 m tall X 0.75 m diameter) circulating fluidized bed gasifier. All the experiments were performed at the temperature range 700-800 °C. A number of experiments were carried out to see the effect of different parameters like coal feed rate, coal particle size on the quality of syngas production during the gasification of coal in circulating fluidized bed gasifier. All the above parametric study performed on three different superficial velocities of 5, 6 and 7 m/s. During the experiments coal feed rate was in the range of 0.036-0.073 g/s and coal particle size was varied from 80-212 mm respectively. With this experiment it is found that with increasing the superficial velocity, the solid circulation rate of material increases as well as with increases in solid inventory. It is observed that coal particle size also affect the heat transfer coefficient means it is decreases with increase the size of coal particle.

Keywords: Coal gasification, circulating fluidized bed, solid circulation rate.

1. Introduction

Coal is a most valuable Primary source of energy. During the gasification coal is converted into syngas. By using the coal, pollution causes so use of coal as an energy source is more and more severe, so clean coal technology gets attention now. In coal gasification solid fuel converts into gas fuels that is known as syngas [1-2]. This fuel gas has many industrial applications like, electricity production, chemical industry, town gas and for residential purpose [3-7]. Gasification has a great history about 200 years [10]. The first fluidized bed was developed in 1920 and after that it is continuously improving [8]. It is a quite popular technology now a days because of their high conversion efficiency. Recently gasification technology shifted from low velocity bubbling fluidized bed to higher velocity circulating fluidized bed, because circulating fluidized bed has lower ash particles emission and higher thermal efficiency [9]. There are many coal gasification system like fixed bed, fluidized bed etc. but Circulating fluidized bed system has great efficiency because it has

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great heat transfer capacity and good solid contact property [10]. The main objective of the present research work is experimental study on Indian coals during gasification in circulation fluidized bed gasifier and justification of parametric effect on coal gasification.

2. Apparatus, Coal Properties and Experimental procedure

2.1 Experimental Setup Description
The lab scale Circulating Fluidized Bed setup under consideration is installed at CSIR-Central Mechanical Engineering Research Institute Durgapur, west-Bengal India. The circulating fluidized-bed riser is made of stainless steel. The riser is 0.75 m in diameter till 2.0 m height and beyond that it is 0.1 m in diameter. Some portions of riser and downcomer are made with transparent Plexiglas to visualize the solids flow. The system consists of a fast bed riser, double cyclones to separate the solid particulates and a downcomer with loop seal. The loop seal is a non-mechanical valve used for control of solid recirculation. The material used for the study of hydrodynamics consists of common silica sand with mean sauter diameter 0.314 mm. Pressures were measured with the help of U-tube manometer connected to the pressure tap located in the loop seal. The experiments were performed with varying riser air velocity but the loop seal aeration was kept constant at 0.3 m/s which was the minimum condition for stability. The material used is common silica sand with range of size of sample between 0.100-0.425 mm. The mean sauter diameter of this sample is 0.314 mm and was obtained experimentally by use of standard sieves. The riser exit is connected tangentially to cyclone in horizontal direction. Bubble cap type air distributor plates at riser and loop seal support the solid particles. The schematic and actual diagram for circulating fluidized bed gasifier system is shown in figure 2 & figure 3 respectively.

2.2 Characterization of material
Indian sub-bituminous coal was prepared for this experimental study. The material was collected from Eastern coalfield limited Raniganj (West-Bengal) and crashed to obtain size before experiment. Before starting the experiment, coal samples were dried in temperature 353 K for 8 hours.

2.2.1 Proximate and ultimate analysis
The proximate and ultimate analysis of coal were carried out using a muffle furnace and a vario MACRO from Elementar Analysis system GmbH according to the standards D-5373. Table 1 shows the basic characteristics of Indian sub-bituminous coal.
Table 1 Proximate & Ultimate analysis

| Proximate analysis | Moisture (%) | Volatile matter (%) | Fixed carbon (%) | Ash (%) |
|--------------------|--------------|---------------------|------------------|---------|
|                    | 2.6          | 41.8                | 53.9             | 2.09    |

| Ultimate Analysis  | Carbon (%)   | Hydrogen (%)        | Nitrogen (%)     | Sulphur (%) | Oxygen (%) |
|--------------------|--------------|---------------------|------------------|-------------|-----------|
|                    | 74.8         | 5.02                | 1.7              | 0.4         | 15.02     |

2.3 Experimental Procedure
Before stating of the experiments, the reaction was heated and then combustion with air was started. Screw feeder controlled the circulation rate of bed material. The temperature range of pyrolyzer and gasifier were constant. During the experiments screw coal feeder adjust the air flow rate and coal feed rate respectively. Ash discharged from system collected by a slag-discharging pipe.

2.3.1 Basic reactions of coal gasification
The gasification of coal mainly consist of two steps first is pyrolysis in the temperature range between 573 and 773 K and second char gasification. During the gasification chemical reaction mainly divided in to two category one is exothermic and second is endothermic. Exothermic process, in which oxygen with carbon and hydrogen. Reaction of oxygen with carbon and hydrogen for endothermic process is shown in equation 1 & 2.

\[ C + O_2 = CO_2 \quad (1) \]

\[ 2H_2 + O_2 = 2H_2O \quad (2) \]

These above two chemical reaction shows the consumption of oxygen. But water gas shift is a completely exothermic reaction as shown in equation 3 and reaction between carbon di oxide with carbon is an endothermic reaction as shown in equation 4.

\[ H_2O + CO = H_2 + CO_2 \quad (3) \]

\[ C + CO_2 = 2CO \quad (4) \]

Basically coal passes many chemical reaction when it reacts with any gasification agents like oxygen and steam. The basic steps of coal gasification in circulating fluidized bed gasifier are described in figure 1.
Figure 1  Reaction sequence for coal gasification in CFB unit.

Figure 2  Schematic Diagram for Circulating fluidized bed.
3. Results and discussion

3.1 Influence of particle size & mass ratio H2O/coal

Basically reaction of vapour with carbon is endothermic as explain in equation 3 & 4. During the gasification of coal when reaction temperature continuously increases contents of hydrogen and carbon mono oxide also increases. But the reaction of vapour with CO is exothermic and its contents decreases with increasing the reaction temperature. Gasification efficiency we can describe as the ratio of chemically bound energy from 1 kg of coal. During the experiments it is observed that different size of coal particles has an alternative effect on carbon conversion rate. Figure 4 shows the effect the particle size on carbon conversion rate. Four different size coal particles (diameter 80, 120, 190 and 211.03 mm) were used during the experiments.
3.2 Solid circulation
With higher superficial velocities the solid carrying capacity increases, which ultimately results in the increase in solids level in the down comer. This exerts a higher hydrostatic pressure on the loop seal to move more solids from the stand pipe. Experimental results show that the solid circulation rate increases with increase of volumetric flow rate in riser air and higher riser air velocity is required for larger particles to maintain the same solid circulations as shown in figure 5. It is also observed during experimentation that the pressure seal of sand in downcomer breaks when the seal aeration is increased continuously without change in riser air velocity.
3.3 Pressure drop across the System

Figure 6 shows the different pressure drop with the aeration rate in bottom of the supply chamber in different part of CFB system. Because of the high circulation rate most of the material were suspended in the riser section during the gasification of coal.
The point-wise observation are summarized below:

- The heat transfer coefficient decreases with increases the coal particle size.
- The solid circulation rate also increases with increasing the operating pressure.
- The effect of the coal rank was less significant in this study.
- The efficiency was almost independent from ungasified carbon (complete combustion or partial combustion).
- During the gasification carbon conversion decreased with the partial combustion of the ungasified carbon.
- Both air/coal ratio and steam/coal ratio has great effect on bed temperature.

4. Conclusions
This study has shown that gasification of Indian coal in circulating fluidized bed gasifier has the potential of becoming an alternative energy source especially in village in developing countries like India. Present research work conclude about the effect of pressure drop, solid circulation rate and effect of particle size during the gasification of coal in circulating fluidized bed gasifier. Experiments were carried out for different particle size (d= 80, 120, 190 & 211.03 mm) and the operation pressure was varied up to 10 k Pa. During the gasification carbon conversion decreased with the partial combustion of the ungasified carbon.

So coal gasification technology is an alternative for using coal in energy applications and all these results that was obtained from these experiments proves the concept correct and feasible and could be performed with a low environmental impact.
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