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Research Paper

Pressurized gasification of lignite in a pilot scale bubbling fluidized bed reactor with air, oxygen, steam and CO_2 agents

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HIGHLIGHTS

- Air, oxygen, steam and CO_2 gases are used as gasification agent.
- Experiment was carried out with 500 kWth capacity pilot scale pressurized gasifier.
- Syngas LHV was varied between 8.2 MJ/Nm^3 and 8.6 MJ/Nm^3.
- Cold gas efficiency is approximately 58.3%.
- Carbon conversion is varied between 72.0% and 84.6%.

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ABSTRACT

In this study, 80 h continuously operated gasification experiment was carried out with pilot scale pressurized bubbling fluidized bed gasifier which was operated with the coal feed capacity of 500–520 kWth (80–83 kg/h coal feed rate). The mixture of air, steam, oxygen and CO_2 was used as gasification agent with different ratios. The operating pressure of gasifier in this experiment was between 2.4 and 2.7 barg. The effects of ER, steam/carbon ratios and CO_2/carbon ratios on syngas composition, carbon conversion ratios and cold gas efficiencies were investigated. According to the results, using CO_2 or H_2O as gasification agent, may have both advantages and disadvantages for the operation. If CO_2 was increased in gasification agent, shift reaction was effected negatively and H_2 products were decreased. If steam was increased, cold gas efficiency was slightly decreased.

1. Introduction

Bubbling fluidized beds (BFB) are widely used for thermal processes, such as drying, combustion, gasification and mineral processing. In industrial applications, gasification process is used for producing syngas from coal or biomass for various applications such as generate heat and power, some chemicals, synthetic natural gas (SNG), hydrogen or liquid fuels production. The properties and composition of the synthetic gas produced by gasification process depend on many factors of design and operational parameter such as the reactor type, the properties and flow rates of feedstock materials and gasifying agents, pressure and temperature in the reactor. In this study, pressurized pilot scale bubbling fluidized bed gasification was investigated for different gasification agents with various ratios.

According to the previous studies published in the literature, air was generally used for gasification agent as the reference base case. The effect of oxygen and steam addition to the gasification agent was investigated as well. Kumar et al. [1] studied the gasification of coal with 80–100 kWth pilot facility using air and steam as gasification agent. Steam to coal mass flowrate and equivalence ratios (ER) are varied between 0.15–0.25 and 0.25–0.35, respectively. According to the results of this study, the calorific value of syngas increase with the decrease of ER value and increase of steam to coal ratio. Similarly, cold gas efficiency increases with the decrease of ER and increase of steam to coal ratio.

Gil et al. [2] reported the result of biomass gasification with the atmospheric bubbling fluidized bed using different gasification agents (air, steam and steam-oxygen mixtures). Their results show that, with the mixture of H_2O and O_2, H_2 and CO concentrations are between 25–30% and 43–47%, respectively. When the pure steam is used as gasifying agent, H_2 and CO concentrations are become 53–54% and 21–22%, respectively.

Campoy et al. [3] represents the effect of oxygen concentration in the gasification agent using oxygen enriched air-steam

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gasification in a bubbling fluidized bed. The ER value and the steam to biomass ratios are varied from 0.24–0.38 to 0–0.63, respectively. They reported that the increase of the oxygen concentration from 21% to 40% increase the cold gas efficiency from 54% to 68%.

Karimipour et al. [4] investigated the effect of steam to O_2 ratio on the quality of syngas produced with fluidized bed gasification of lignite. Their study was performed with the steam to O_2 ratio between 0.5 and 1.0. They concluded that the carbon conversion increases with the increase of steam/O_2 ratio. H_2/CO ratio strongly related with the steam/O_2 ratio. Kern at al. [5] studied the gasification of lignite with the 90 kWth dual fluidized bed gasifier. Steam to carbon mass ratio is varied between 1.3 and 2.1. According to their results, decreasing the steam/carbon ratios increase the cold gas efficiency. When this result is compared with the previous studies, it could be concluded that there is an optimum value of steam/coal ratio, apart from this at which higher or lower ratios result in the decreases in the cold gas efficiency. Arena et al. [6] studied the air gasification process of municipal waste in a pilot scale bubbling gasifier with the capacity of 70 kg/h and 400 kWth. They studied with the ER value and the bed temperature of 0.25–0.33 and 850–930 °C, respectively. The lower heating value (LHV) of syngas and the cold gas efficiency of gasifier are about 5 MJ/Nm^3 and 60%, respectively. Carbon conversion achieved during the experiments is varied between 80 and 90%.

There are many other studies related with the investigation of the effect of the temperature of gasification reactor [7–9], equivalence ratio [10–13] and steam to carbon ratio [14–16]. Most of the these research in literature carried out on the bench-scale and/or laboratory scale systems, except in some of these studies [8,9,15,17,18] used pilot scale gasification system with thermal capacities relatively higher than the others (80–100 kWth).

In this study, the test results of a pressurized bubbling fluidized bed gasification system with 500–520 kWth fuel feeding capacity was analyzed for 80 h continuously operation period by using air, oxygen, steam and CO_2 mixture as gasification agent with different ratios. Normally, gasifier was designed for generating syngas for coal to liquid process including gas cleaning, gas conditioning and FT processes. Just before the FT reactor, there was a high pressure compressor in order to pressurize the syngas (up to 30 barg). Due to the pressure losses up to the FT compressor, gasifier has to be work at approximately 2.5 barg. Because of that, 2.5 barg pressure level was selected as operating pressure in this study and gasifier was tested independently from the other processes.

The capacity of the system is relatively higher than that of most of the research published in literature. So, the test results of pilot system may provide valuable insights into the process and operation of larger scale gasification systems.

2. Experimental

2.1. Materials

Silica sand was used as bed material which had size distribution between 0.3 mm and 0.7 mm and weighted arithmetic mean diameter of 644 μm according to the sieve analysis. Bulk and particle densities were 1450 kg/m^3 and 2545 kg/m^3, respectively. Turkish lignite (Soma lignite) was used as feedstock which had the LHV of 5195 kCal/kg. The proximate and elemental analyses of selected lignite are shown in Table 1. The particle size of coal fed to the gasifier was in between 0.5 mm and 1 mm.

2.2. Experimental setup

The schematic of the pilot scale pressurized bubbling fluidized bed gasifier system is shown in Fig. 1. The system consists of BFB reactor, cyclone separator, syngas cooler, quencher, syngas burner, fuel feeding system, ash removal system and gasification agent (air, steam, O_2, CO_2) preheating systems.

The BFB reactor is 3500 mm in high. Inner diameters of dense bed and freeboard regions of the reactor are 300 mm and 450 mm respectively. There is a cyclone separator with 140 mm inner diameter. Just after the cyclone separator, there is a syngas cooler for cooling down the syngas temperature from approximately 800 °C to 300 °C. The final stage of the system is quencher which is used for cooling syngas to approximately 30–40 °C with spraying the cooling water.

An air compressor was used for the supply of pressurized air. The flowrate of the air was measured and controlled with a mass flow controller (MFC). Oxygen and CO_2 gasses were supplied by two different gas storage tanks. A steam generator was used for the steam supply at the saturated conditions (at the pressure of 6 barg and the temperature of 165 °C).

In the BFB reactor, the mixture of fluidization gas passed through the windbox and the distributor plate to the reactor. The distributor plate was made out of stainless steel and has 100 standpipes with 4 nozzles which are 1 mm in diameter. There were ten temperature measurement points located on the system in order to measure the temperatures of ambient air, 1st heater exit, 2nd heater exit, lower dense bed, upper dense bed, lower freeboard, upper freeboard, cyclone exit, heat exchanger exit and quencher exit, respectively. Pressure measurement device were also located on the same points with the temperature sensors. The reactor pressure was controlled by the pressure control valve located at the syngas exit just before the syngas burner. The system was monitored and controlled with the distributed control system (DCS). The gas analyzer was used for measuring the syngas composition. SIEMENS Process Chromatography Maxum Edition II was used to analyze syngas composition. It measures H_2, O_2, CO, CO_2, N_2, CH_4 and C_{6+} with a specific Thermal Conductivity Detector (TCD).

2.3. Experimental method

2.3.1. Startup of the gasification reactor

In the gasification experiment, 80 kg bed material (silica sand) was loaded to the reactor which had the initial static bed height of approximately 530 mm. Air flowrate was adjusted in order to get 0.8 m/s superficial gas velocity at the dense bed region of gasifier at the atmospheric conditions (20 °C, 0 barg). At this condition, the bed material was in bubbling regime. In order to heat up the bed material to the ignition temperature of coal, the electric heater was used for preheating the fluidization air. There were 2 groups of electric heaters; each consists of three serial connected 20 kW electric heaters. With these electric heaters, the fluidized bed temperature was increased to 350 °C which was the practical limit of

Table 1
Proximate and elemental analysis of selected Turkish coal (mass basis).

Proximate analysis	Moisture (%)			Volatile matter (%)		Fixed carbon (%)		Ash (%)
	6.6			38.15		42.6		12.65
Elemental analysis	C (%)	H (%)	O (%)	S (%)	N (%)	H_2O (%)	Ash (%)	LHV (kcal/kg)
	60.56	3.89	14.32	0.92	1.06	6.60	12.65	5195