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PARTIAL GASIFICATION OF DIFFERENT TYPES OF COALS IN A FLUIDISED BED GASIFIER

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ABSTRACT

Partial gasification of Adaro, Dasa Eka Jasatama (DEJ), Hunter Valley, Merit Pila and Mukah Balingian coals have been studied in a laboratory-scale, atmospheric fluidized bed gasifier using air and air-steam as fluidizing media. Determination of the producer gas compositions were conducted using Gas Chromatography. Partial gasification experiments were conducted at bed temperature of 600°C. The comparison of the producer gas compositions while using air and air-steam gasifying agents were conducted. Introduction of steam had shown significant increased on the CO, CO_2, CH_4 and H_2 contents in the producer gas compared with the air as the sole gasifying agent.

Keywords: *Coal, fluidized bed, gasification, air, steam*

1.0 INTRODUCTION

Coal gasification is a clean technology that presents good prospects of coal use, mainly for producing electricity with a high coal conversion efficiency and low environmental impact. It is a technology to convert coal (solid fuel) into flammable gas and could be applied to combined cycle power generation with this fuel. Coal, steam and oxygen (or air) are reacted together to produce a gas containing hydrogen, carbon monoxide, carbon dioxide, nitrogen, methane and other hydrocarbon compounds. This gas is cleaned to remove particulates and sulfur compounds. Gasification technologies can use all types of coal. It can be linked with combined cycles (integrated combined cycle) to produce power efficiently or it can be used as a source of synthesis gas for chemicals or fuel gas for homes and industry. Gasification technology offers the prospect boosting efficiencies to 45 to 50% in the short term and potentially to nearly 60% with technological advancements [1].

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This study was conducted in alignment with the advanced version of the combined-cycle plant involves partial gasification of coal in a pressurized pyrolyzer instead of its complete gasification as done in an IGCC [1]. According to Basu [2], typical gasifier pyrolysis or partial gasification process take place at temperatures of 150-700°C. With that the selected be temperature of 600°C were used through out the study to represent the partial gasification process.

The aim of this study are (a) to determine the producer gas compositions and (b) to study the influence of the different gasifying agents in the partial gasification process.

2.0 THEORY OF PARTIAL GASIFICATION (PYROLYSIS)

Pyrolysis (also called *partial gasification*) was first observed in the 17th century and was later used by Murdoch in 1797 to produce gas for street lighting, and then by Gesner in 1846 to produce clean, transportable oil for homes and other uses [2].

A series of complex physical and chemical processes occur during the pyrolysis processes, which start slowly at less than 350°C, accelerating to an almost instantaneous rate above 700°C [2]. The composition of the evolved products is a function of the temperature, pressure and gas composition during pyrolysis. The pyrolysis process is initiated at around 230°C, when the thermally unstable components, such as lignin in biomass and volatiles in coal are broken down and evaporate with other volatile components. The heating value of the gas produced in pyrolysis is low which is about 3.5 to 9 MJ/m^3. This process can be represented by the following general reaction:

Coal (or biomass) + Heat $\rightarrow$ Char + Gases + Vapors or Liquid

(Coke Ash) Liquid (PAH, Tar)

(CO, CH_4, H_2O, CO_2)

Pyrolysis generally produces the following three products :

1. Light gases such as H_2, CO, CO_2, H_2O and CH_4
2. *Tar*, a black, viscous and corrosive liquid composed of heavy organic and inorganic molecules
3. Char, a solid residue mainly containing carbon

Various studies had been conducted on the pyrolysis processes of coal, biomass, oil shale and other potential fuel, using fluidised bed gasifier [3-7].

3.0 EXPERIMENTAL WORK

Three ranks of coals were used in this study. There are sub-bituminous B coals (Merit Pila, and Mukah Balingian), sub-bituminous A coal (Adaro) and bituminous (Dasa Eka Jasatama, DEJ and Hunter Valley) coals. The typical characteristics of these coals are shown in Table 1.

Table 1: Typical properties of coals

Coals	Adaro	DEJ	Hunter Valley	Merit Pila	Mukah Balingian
Calorific value kcal/kg	5927	6523	6763	5800	5030
Proximate analysis (%):					
Moisture	11.4	3.9	2.9	14.6	15.3
Volatile matter	42.0	41.0	29.9	41.4	34.3
Fixed carbon	44.6	42.3	54.2	39.6	42.4
Ash	2.0	12.8	13.0	4.4	8.2
Ultimate analysis (%):					
Carbon	62.9	65.6	70.3	55.3	54.6
Hydrogen	5.3	5.3	4.6	5.1	4.9
Nitrogen	0.8	1.2	1.6	1.1	1.3
Sulphur	0	0	0	0	0

The experimental work was carried out in a laboratory scale fluidized bed gasifier, which consists of seven main parts (as shown in Figure 1): (i) fluidized bed gasifier, (ii) screw-feeder, (iii) steam generator, (iv) air-blower, (v) electric heaters, vi) cyclones and (vii) gas sampling ports.

The internal diameter of the gasifier is 0.25 m and its height is 1.0-1.2 m as shown in Table 2. It was built with stainless steel internally covered with a 10 cm layer of refractory cement. A gas distributor with 7 holes of 1 mm diameter was placed between the conical bottom and the cylindrical section of the gasifier. Two thermocouples were placed at the bed area and one thermocouple at the freeboard area. Other thermocouples were placed at the conical section and at the freeboard exit. The steam for the partial gasification was supplied from the electrical steam generator. The flow is controlled by a valve system.

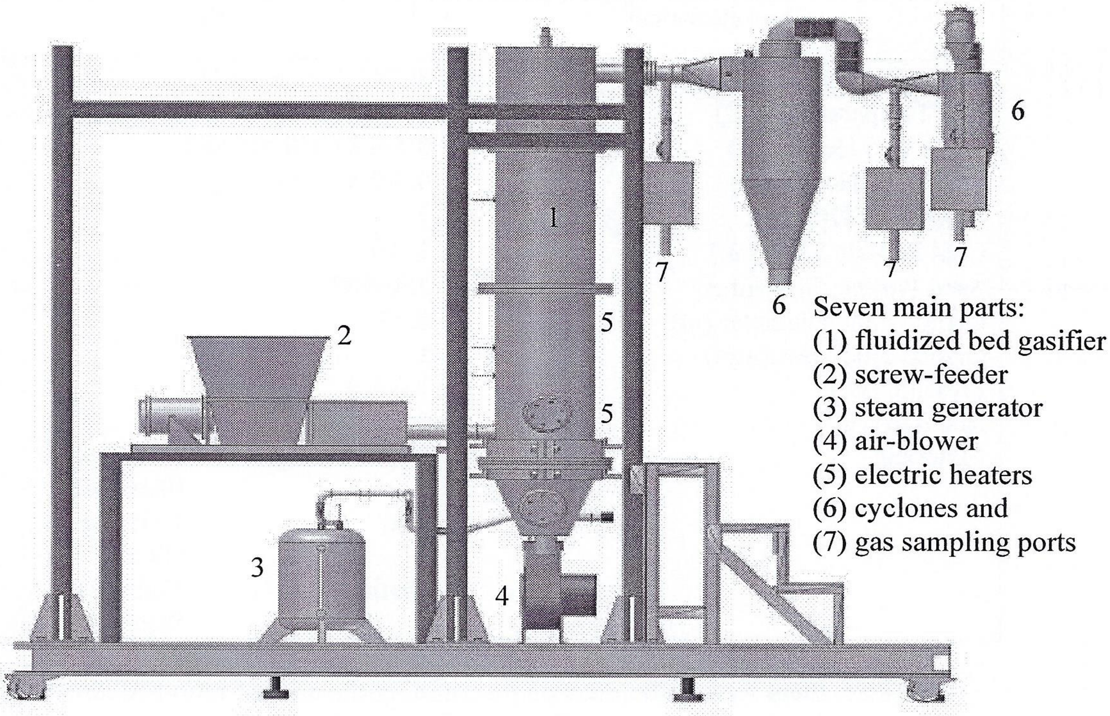

Figure 1: The experimental test rig

Continuous monitoring of the producer gas, such as CO, CO_2 and total hydrocarbon, THC was conducted using on-line portable gas analyzer. The detail analysis of the producer gas compositions were performed using gas chromatography.

During the starting period, about 10 kg of sand contained in the gasifier was heated up using heated air, generated in the chamber. Before entering the orifice plate, flow rate of the blowing air was controlled at 20 hertz and heated to 150°C using electric heater. Before the coal was feed, the bed temperature was increased to 600°C using electric heaters. The bed temperature was controlled to be isothermal at 600°C. After the fluidizing was stabled inside the bed area (view from the gasifier top), about 1.0 kg of coals was fed. The feed rate of coal was measured by means of a screw-feeder. After 3 minutes, the coal started to react with the hot sand in the fluidizing area. All the electric heaters were maintained at the mentioned temperatures through out the experiments. Gases leaving the freeboard section is passed through two cyclones in series to trap entrained particles. About 20 minutes, the gasification process started to achieve steady state. The gasifier was in steady state when the bed temperature and the gas concentrations are substantially constant [8]. After the gasifier achieved the steady state, the flow of steam about 4 kg/hour steam was added. Then, the produced gas was collected and to be analysed using gas chromatography.

Table 2: Design parameters of the gasifier

Characteristics	Values	
Power Supply	8kW / 3 phase / 415 V	
Bed Temperatures (°C)	750-1000	
Static Bed Height (m)	0.5-0.8 (with flange)	
Freeboard Height (m)	0.5-0.8 (with flange)	
Number of Orifice	7	
Coal Particle Size (μm)	1250	
Sand Particle Size (μm)	350-500	
Orifice Plate Diameter (m)	0.25	
Orifice Thickness (mm)	1	
Pressure (Bar)	1.0-1.5	
Bed Area (m^2)	0.05	
Materials	Outer Casing	Mild steel & fiber sheet
	Bed	Ceramic & NiCrN
	Orifice Plate	Stainless Steel

However, there were difficulties on determining the air/fuel ratio and air/steam and even cold gas efficiency of the partial gasification process during the experiments, due to the flow meters for air blower and steam flow were not installed to the gasifier [9]. Besides that this gasifier has a capability to gasify the solid fuel at the controlled temperature and released the producer gas for the quality evaluation. The LCV of the producer gas were calculated using the molar ratio of the gas compositions as presented elsewhere [10].

Partial gasification tests were carried out using Adaro, DEJ, Hunter Valley, Merit Pila and Mukah Balingian coals.

4.0 RESULTS AND DISCUSSION

Partial gasification of Adaro, DEJ, Hunter Valley, Merit Pila and Mukah Balingian coals were investigated using Atmospheric Fluidized Bed Gasifier. Producer gas composition in air and air-steam partial gasification were shown in Table 1 and 2. The formation of compounds such as carbon monoxide, CO; carbon dioxide, CO_2; hydrogen, H_2; oxygen, O_2; nitrogen, N_2; methane, CH_4; ethylene, C_2H_4; ethane, C_2H_6; and acetylene, C_2H_2 have been considered. During the air partial gasification processes H_2, CO, CH_4 and CO_2 had shown higher content compared to the other gaseous components. The formation of combustible gases, such as CO, H_2 and CH_4 were discussed in detail, since these gases were most important in the combustion system, as shown in Figure 2 and 3.

Table 3: Producer gas compositions from air gasification using different coals

Producer Gas Compositions (mol.%)	Coal Types				
	Adaro	DEJ	Hunter Valley	Merit Pila	Mukah Balingian
H_2	9.4	14.8	2.1	2.6	1.9
O_2	1.9	1.0	2.9	7.7	5.7
N_2	80.4	72.8	88.2	82.9	85.4
CO_2	1.5	3.6	4.5	3.6	4.4
CO	4.0	4.5	1.7	2.9	2.2
CH_4	2.2	2.3	0.5	0.3	0.2
C_2H_4	0.5	0.8	0.1	0.1	0.1
C_2H_6	0.1	0.1	0.0	0.0	0.0
C_2H_2	0.0	0.1	0.0	0.0	0.0
H_2/CO ratio	2.4	3.3	1.2	0.9	0.9
LCV_{PG} (MJ/NM^3)	2.3	3.0	0.6	0.8	0.6

The products formed from the synthesis gas depend both on the hydrogen-to-carbon monoxide ratio in the gas as well as on the catalyst and reactor conditions selected. Hydrogen-to-carbon monoxide mole ratios range from 0.5 to 1 for gasoline production with rejection of carbon dioxide, to 3 for methane production with rejection of water. The required hydrogen-to-carbon monoxide ratio can sometimes be achieved directly in the gasifier, although a H_2/CO ratio as high as 3 is normally not produced in commercial systems [11]. In fact, many gasifiers produce a gas having a H_2/CO ratio less than 1. In these cases an adjustment to the H_2/CO ratio is normally required, and is done by adding steam to the synthesis gas and reacting it with the carbon monoxide to form hydrogen and carbon dioxide :

$$CO + H_2O(g) \leftrightarrow CO_2 + H_2 \qquad \Delta H^o_{298} = -41.2 \text{ KJ/mol} \tag{1}$$

This is the gas shift reaction, also called the water-gas shift or just shift reaction.

In this study, H_2 content was high in the air partial gasification processes followed with CO and CH_4. The molar ratio of H_2/CO for air partial gasification were higher than 1 for Adaro, DEJ and Hunter Valley coals, which shows early indication that the synthesis gas more suitable raw materials for chemical synthesis [11, 12]. While molar ratio H_2/CO for Merit Pila and Mukah Balingian were lower than 1, which shows early indication that the synthesis gas more suitable as fuel gas for electricity generation [12].

In air-steam partial gasification process the combustible gas, H_2 contents were still dominating and the molar ratio of H_2/CO for all the coals were increased, higher than 1, the molar ratio of H_2/CO for Merit Pila coal and Mukah Balingian coal were below 1, which shows early indication that the synthesis gas more suitable as fuel gas for electricity generation than as raw materials for chemical synthesis [12].

Table 4: Producer gas compositions from air-steam gasification using different coals

Producer Gas Compositions (mol.%)	Coal Types				
	Adaro	DEJ	Hunter Valley	Merit Pila	Mukah Balingian
H_2	19.9	9.3	4.7	9.8	7.6
O_2	3.2	5.9	7.4	1.5	4.3
N_2	61.9	71.4	78.1	68.3	71.8
CO_2	2.5	2.1	2.3	4.9	4.3
CO	9.2	5.1	3.8	6.0	7.0
CH_4	2.7	4.0	2.7	7.9	3.7
C_2H_4	0.7	1.8	0.8	1.0	1.0
C_2H_6	0.0	0.3	0.3	0.5	0.3
C_2H_2	0.0	0.0	0.0	0.0	0.0
H_2/CO ratio	2.2	1.8	1.2	1.6	1.1
LCV_{PG} (MJ/NM^3)	4.3	3.1	2.0	4.7	3.1

The fuel gas produced from air-blown gasifier is classified as low calorific value (LCV). According to Xiao, such fuels present special difficulties for combustion due to the low combustion temperature and small combustion rate, with flame stability problems and low combustion efficiency [13]. However, with the introduction of steam, the LCV increased as presented in Table 2 and 3. The calculated LCV from this study were in agreement with the finding of Xiao.

During the air partial gasification process combustible gases which are H_2, CO and CH_4 were increased as the LCV_{PG} were increasing, as shown in Figure 3. The LCV_{PG} had shown significant increased as the steam was introduced into the partial gasification process (Figure 3). H_2 was dominating when air and steam were used as the gasifying agents. These behaviour can be related to the favorable of the water-gas reaction and shift conversion reaction as shown in Equation (2) and (3).

$$C + H_2O \leftrightarrow H_2 + CO \qquad -13138 \text{ kJ/kg mol carbon} \qquad (2)$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad -4198 \text{ kJ/mol} \qquad (3)$$

The results obtained agree fairly well with those of literature though referring to different system [14-18]. Crnomarkovic *et al.*, found that the introduction of steam had influenced the following: rise of H_2, CO and decrease of CO_2 [19]. Increase of H_2 and CO contents in the produced gas are probably influenced by steam reaction with carbon ($H_2O + C \rightarrow H_2 + CO$). The increase of H_2 content could have come as a result of steam reaction with CO ($H_2O + CO \rightarrow H_2 + CO_2$). While the increase of CO was probably a result of CO_2 reactions with carbon ($CO_2 + C \rightarrow 2CO$). The LCV of the producer gas also within the range

(2-4 MJ/Nm^3) of the previous studies as reported by Ocampo *et al.* [8] and Kim *et al.* [9].

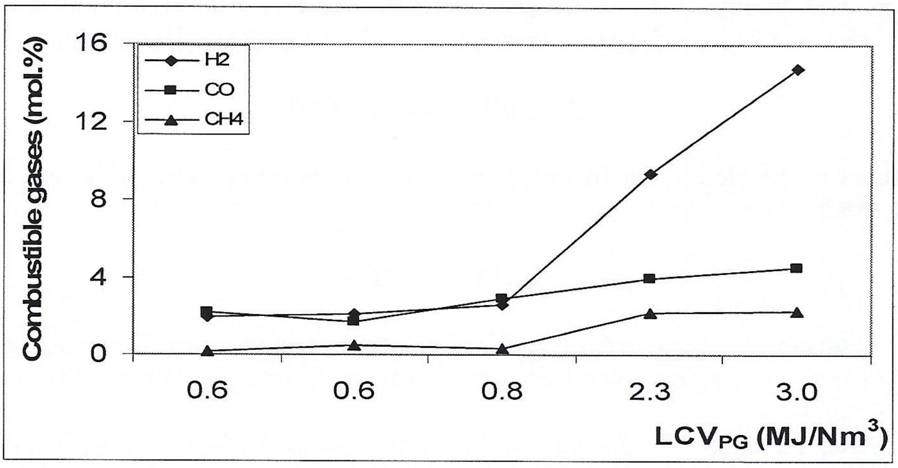

Figure 2: Combustible gases content against the LCV_{PG} during the air partial gasification

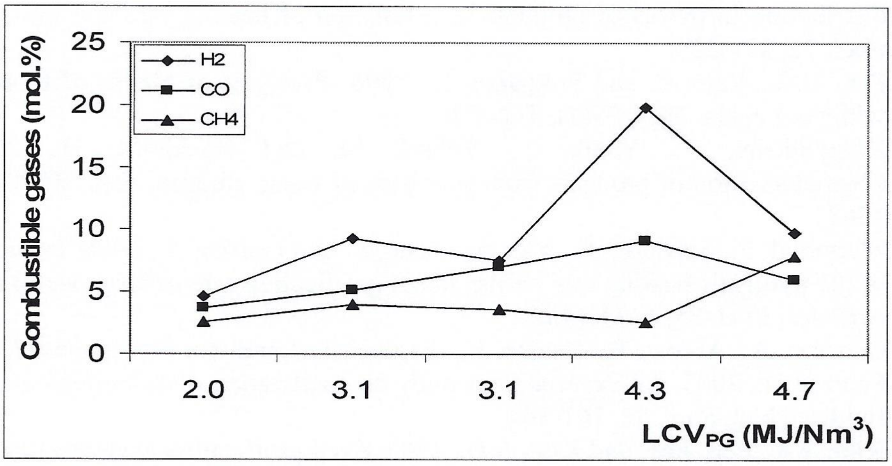

Figure 3: Combustible gases content against the LCV_{PG} during the air-steam partial gasification

5.0 CONCLUSION

A laboratory scale fluidized bed gasifier has been developed and operated for partial gasification of coal with air and steam as the gasifying agents. The performance parameter, which is the product gas composition have been studied.

In this study, it was found that the combustible gases, H_2, CO and CH_4 were significantly higher in air-steam partial gasification process compared to the air partial gasification process. The effect of the coal rank was less significant in this study. The quality of the producer gas which was assess through the calculated LCV also had improved, as the steam was introduced as the gasifying agent.

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