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DEVELOPMENT OF ALLOTHERMAL GASIFICATION BY A DUAL FLUIDIZED BED TECHNOLOGY

PENGEMBANGAN GASIFIKASI ALLOTHERMAL DENGAN TEKNOLOGI DUAL FLUIDIZED BED

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ABSTRACT

Allothermal gasification is a gasification process which separates oxidation process and other processes. So that, synthesis gas (syngas) could be produced from gasification with air as gasification agent. The main feature of allothermal gasification is how to transfer the heat of oxidation reaction to supply heat required for drying, pyrolysis and reduction processes. One of the techniques is to circulate bed material using a dual fluidized bed. Pressure loop and syngas composition resulted from gasification test is discussed. Pressure loop data of the Process Development Unit (PDU) facility showed a stable condition and resulted a continous circulation of the bed material. Therefore, heat transfer of oxidation reaction into a gasifier proceeded in a continous and stable way. A good heat transfer of the heat of oxidation reaction resulted a good quality of syngas where the composition of H_2 was close to 50% and the ratio of H_2/CO was >2% which is suitable for chemical feedstock.

Keywords : coal gasification, allothermal, dual fluidized bed, process development unit, pressure loop, syngas

SARI

Gasifikasi allothermal *merupakan proses gasifikasi yang memisahkan proses oksidasi dari proses lainnya, sehingga pembuatan gas sintesis (*syngas*) dapat dihasilkan dari gasifikasi menggunakan media oksidasi udara. Masalah utama pada gasifikasi* allothermal *adalah teknik pemindahan panas reaksi oksidasi untuk memasok kebutuhan panas pengeringan, pirolisis dan reduksi. Salah satu teknik pemindahan panas reaksi ini adalah menggunakan sirkulasi bahan unggun pada dua reaktor* fluidized bed *(*dual fluidized bed*). Parameter kinerja yang dibahas adalah* pressure loop *dan komposisi gas sintesis. Data* pressure loop *peralatan* Process Development Unit *(PDU) gas sintesis terlihat stabil dan menghasilkan sirkulasi unggun pasir yang berlangsung secara kontinyu, sehingga perpindahan panas reaksi oksidasi ke gasifier terjadi secara kontinyu dan stabil. Perpindahan panas reaksi oksidasi yang baik menghasilkan kualitas gas sintesis yang baik pula, yaitu komposisi H_2 (50%) dan perbandingan H_2/CO yang besar (>2), sehingga gas sintesis cocok dimanfaatkan sebagai bahan baku kimia.*

Kata kunci: gasifikasi batubara, allothermal*,* dual fluidized bed*,* process development unit*,* pressure loop*, gas sintesis*

INTRODUCTION

Coal gasification is a reaction of coal with gasifying agent such as a mixture of air and steam and/ or O_2 and steam) converted into a mixture of a higher calorific value gases. Gasification process consists of several steps, namely drying, pyrolysis, reduction and oxidation which may occur separately or simultaneously. In compliance with conventional gasification technology, all these steps are conducted in a single reactor. Therefore, in order to obtain free-nitrogen-syngas product, it is required pure oxygen which is resulted from an air separation unit. Allothermal gasification is a

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gasification process which separates oxidation and other processes. Oxidation process takes place in a combustor, while reduction or gasification process occurs in a gasifier. This process is shown in Figure 1. The advantages of this technology are not necessary to build an air separation unit, operate at mild temperature below 1000°C and low pressure near atmospheric. Further, this will cause the reduction of CAPEX (Suda et al., 2007).

The main feature of allothermal gasification is the way of transferring the heat of oxidation reaction to supply heat required for drying, pyrolysis and reduction. One of the ways to transfer heat is using bed material circulation in two fluidized bed reactors. Therefore, this technology is known as dual fluidized bed (Kern et al., 2010). This technology has been widely studied in the recent years. Some of those similar technologies have been developed in a pilot plant scale by other researchers such as SilvaGas (Paisley et al., 2001), FICFB (Hofbaeur et al., 2002) dan TIGAR® (Fujimori et al., 2007). In 2012, Puslitbang *tek*MIRA has succesfully developed a Process Development Unit (PDU) facility for gasification with a dual fluidized bed technology (Diniyati, et al., 2012) having a capacity of 5 kg coal/h. This paper will discuss the results of the allothermal gasification process in the PDU in particular the investigation of the pressure loop and syngas composition produced from the gasification test.

METHODOLOGY

Materials

River sand was employed as bed material. The sand was characterized by having high silica oxide content of almost 48% and having low alkali oxide compounds, while the content of alkali earth oxide compounds were higher than those of alkali oxides. Thus, the sand was crushed and screened to get a size of 250 – 500 μm. The specification of the sand used is presented in Table 1. Meanwhile, for the gasification test, low rank coal was used. The proximate and ultimate analyses of the coal used in this study is indicated in Table 2. As for the low rank coal, the moisture content of the sample was quite high and the ash content was less than 5% which is rather low.

Equipment and Methods

The pressure loop and gasification test was conducted in a PDU gasification with a dual fluidized bed technology. A simplified process flow diagram of the PDU facility is shown in Figure 2. The main

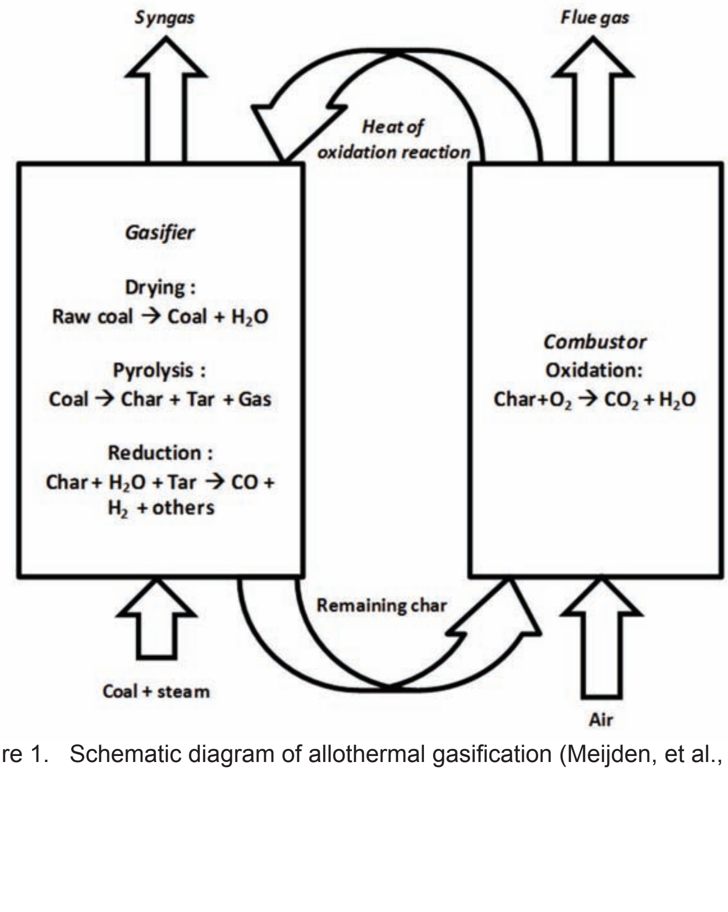

Figure 1. Schematic diagram of allothermal gasification (Meijden, et al., 2008)

Table 1. Specification of the river sand

Chemical composition, wt%								Particle size, μm	Bulk density, kg/m^3
SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	CaO	MgO	LOI		
47.8	14.43	11.45	0.86	2.22	6.47	5.34	5.83	250 – 500	1,222

Table 2. Characteristic of the coal used

Proximate analysis, wt%, adb				Ultimate analysis, wt%, daf					Calorific value kcal/kg, adb	Particle size, mm	Bulk density, kg/m^3
Moisture	Ash	Volatile Matter	Fixed carbon	C	H	N	S	O*			
24.20	4.86	36.12	34.82	73,36	9,02	1,09	0.16	16.38	4,506	2 – 5	910

*by difference

unit of the PDU consists of a gasifier, a riser, and two cyclones. Gasifier is a bubbling fluidized bed reactor comprising a reaction chamber and a freeboard. Reaction chamber and freeboard have the size of length, width and height of 100 mm, 400 mm and 1000 mm, respectively. Meanwhile, riser is a circulating fluidized bed reactor which has an inner diameter of 50 mm and a height of 7500 mm. The lower part of the gasifier and riser are connected with a loopseal to control the rate of bed material circulation.

Gasifier, riser, loopseal and piping system were built from an iron based material (seamless pipe and esser plate). Reaction chamber is equipped with an electric heater to reduce the heat radiation to the environment. Meawhile, the other parts of the PDU facility are insulated with calcium sili-

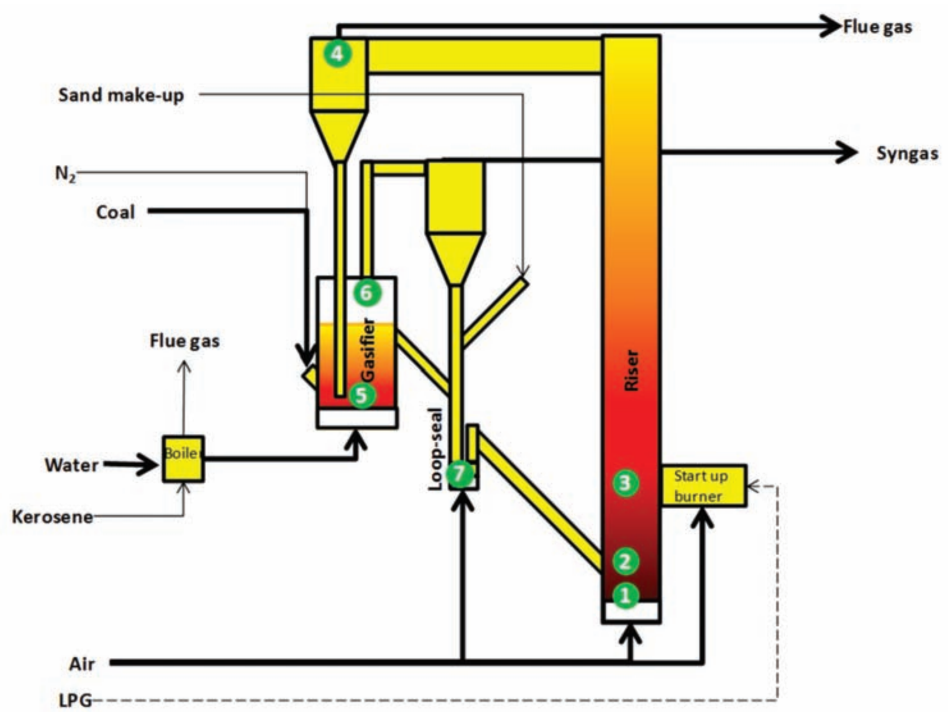

Figure 2. Schematic diagram of gasification process using a dual fluidized bed

cate board. Steam feed rate was supplied from a boiler generated by kerosene with the production capacity and pressure reached 10 ton steam/h and 5 bar (g).

Pressure gauge was placed in 7 (seven) points to measure the pressure in that point, respectively as shown in Figure 2. For determination of the pressure loop, air was flown, thus river sand was circulated without coal and steam. The pressure indicated at each point was observed. This test was conducted at room temperature.

Meanwhile, for the gasification test, initially, air was flown to the riser, loopseal and gasifier. This was only done at the start-up. Thus, sand was fed through inlet sand make-up. The sand was circulated to the riser and gasifier. After the sand circulation achieved the steady state condition, the PDU facility was heated up by burning LPG in the start-up burner. Afterwards, the heater of the gasifier was turned on. After the temperature reached 500°C, air flow in the gasifier was switched with steam as the gasifying agent. Flow rate of the primary and seconday air were 22 and 14 Nm^3/h, respectively. The operating conditions of the gasification test are indicated in Table 3.

Table 3. Operating conditions

Parameter	Value
Flow rate	
- Primary air in the riser, Nm^3/h	22
- Secondary air in the riser, Nm^3/h	14
- Air flow rate in the loopseal, Nm^3/h	1.5
Coal feed rate, kg/h	5

After the gasifier temperature reached the required temperatures, i.e. 700 – 800°C, coal was fed into the gasifier with the feed rate of 5 kg/h. Coal was then reacted with steam and converted into syngas. This reaction was an endothermic reaction which required heat. The remaining coal char together with the river sand were then circulated then returned to the riser through a loopseal. Then, the coal char was burnt in the riser, resulting the increase of temperature up to 900°C. The heat release from the char combustion was absorbed by the river sand, thus the sand was circulated and supplied the heat required for the gasification. This cycle repeated during the process proceeded. Syngas produced from the gasification process was analyzed using an online mini gas chromagraph (Wuhan, Infrared Multi-components gas analyzer Gasboard-3100). In this study, the pressure loop and syngas composition were investigated. Pressure loop indicates a pressure equilibrium from all points in the PDU facility. Therefore, the sand could circulate continously. In the meantime, syngas composition shows the quality of the gas produced from the gasification process.

RESULTS AND DISCUSSION

Characteristics of Pressure Profile of the PDU Facility

Figure 3 shows the pressure profile resulted in the commissioning test. It is shown from the figure that the riser pressure decreased sharply from the air box (number 1) to the inlet of the secondary air (number 3) and decreased sluggishly up to an atmospheric pressure in the outlet of the cyclone (number 4). This occurrence could be explained that at the lower part of the riser (from the distributor to the inlet of the secondary air) was a dense zone, while the upper part of the riser (the inlet of the secondary air to the cyclone) was a dilute zone. In the hydrodynamics point of view, dense zone is similar to the bubbling fluidized bed condition which has a wide particle distribution (Kehlenbeck et al., 2001). Meanwhile, dilute zone is hydrodynamically classified into fast fluidization zone which oppositely has a narrow particle distribution (Schmid et al., 2011).

Sand circulation from the riser cyclone (point number 4) subsequently flew to the gasifier and was fluidized by steam introduced through the distributor (point number 5). Since the sand circulation from the riser cyclone to the gasifier was undergoing continuously and because the bed height of the bed material at bubbling fluidized bed condition must be kept at a constant level, so that the overflow of the sand (point number 6) was transported from the freeboard of the gasifier to the standpipe of the gasifier cyclone through a loopseal. Loopseal has to circulate the bed material from the freeboard of the gasifier having a lower pressure (point number 6) to the riser having a higher pressure (point number 2). This phenomenon could happen since the bed material forming a moving bed condition in the standpipe. The height of the bed in the freeboard

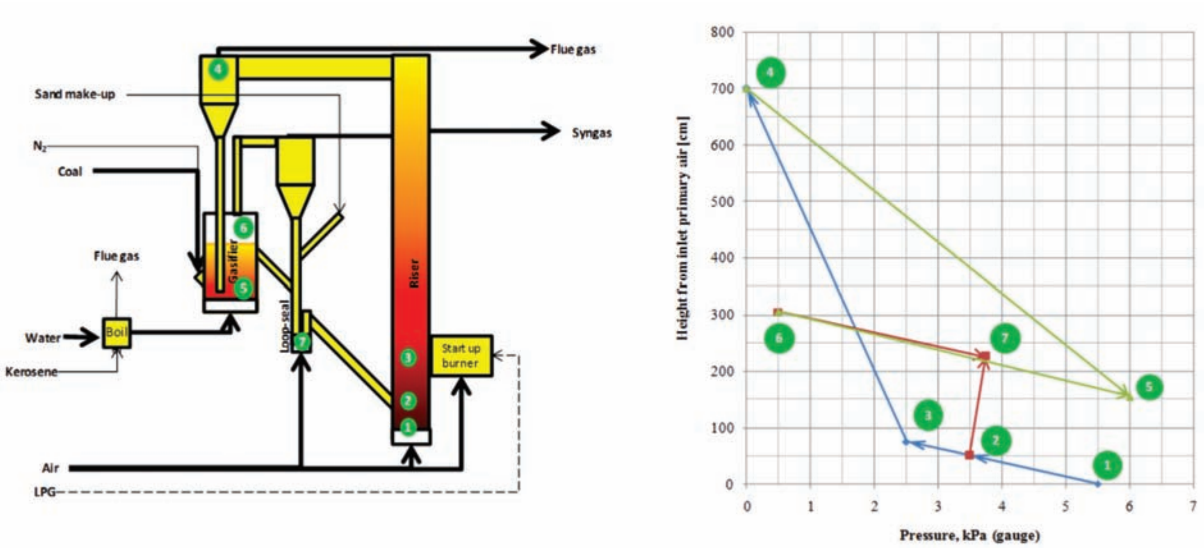

Figure 3. Pressure loop within PDU facility in the commissioning test

of gasifier became an important factor to suppress the high pressure of the riser. The higher the riser pressure, the higher the height of the bed required in the standpipe. In addition, loopseal has also an important role to control the circulation rate of sand by changing the air flow rate passing through a loopseal. The higher the air flow rate, the higher the circulation rate of sand. Due to this function, loopseal is often called as a non mechanical valve (Basu, 2006). Pressure profile at the points number 2-3-4-5-6-7-2 formed a loop so that this is known as a pressure loop.

Gasification Test

Sensible heat released from char combustion in the riser was carried by sand. The heat carried by sand was used for supplying heat for gasification reaction in the gasifier, to react coal with steam and produced syngas. Syngas specification produced from the gasification test during the commissioning test can be seen in Table 4 in comparison with the results of similar and different gasification technologies, namely TIGAR® (Suda et al., 2007) and commercial Lurgi Dry Ash Gasification (Higman and van der Burgt, 2008).

The results show that the composition of H_2 is 45.82%, close to 50%. These data show a typical allothermal gasification process data similar with the composition of the TIGAR® syngas (51%). Meanwhile, CO composition shows much lower than that of the TIGAR® syngas (18%). This might be due to the operating temperature was much lower (650°C) than the expected temperature of 800°C. So that the reaction kinetic/CO formation rate was still low at that temperature. Further, at such operating temperature, CO_2 formation was quite high, 37.72%, almost twice compared with that of TIGAR® (19%). On the other hand, the composition of H_2 (45.82%) and ratio of H_2/CO (6.33) resulted are higher than the results of conventional gasification technology such as Lurgi Dry Ash, namely 37.2% and 1.88. These results indicate that the allothermal gasification process occurred as expected in the PDU facility, where coal reacted with steam without contaminated by air from char combustion in the riser (Hofbauer and Rauch, 2000). The higher values of H_2 composition and H_2/CO ratio will consequently reduce the capacity of the water gas shift reaction in the syngas processing into chemicals.

The high H_2 composition and the high ratio of H_2/CO show that the resulted syngas is suitable for chemical feedstocks. Moreover, the high composition of the hydrocarbons gases (CH_4 and CnHm) indicates that there were still a lot of the pyrolysis gas products that were not converted yet. This is due to the low gasification temperature at around 650°C.

In the test, the gasifier temperature could not increase to the required temperature (800°C). This was caused by the limitation of the material specification (iron-based material) used to build the

Table 4 Specification of syngas product composition

Parameter	Value	TIGAR®	Lurgi Dry Ash Gasification
Gas composition, vol%			
H_2	45.82	51	37.2
CO	7.23	18	19.7
CO_2	37.72	19	30.4*
CH_4	7.87	9	11.8
O_2	0.01		
CnHm	1.31	3	0.4
N_2 **	0.04		0.5
Calorific value, MJ/Nm^3	9.55	12.6	n.a.
H_2/CO	6.33	2.83	1.88

* CO^2 + H_2S; **by difference; n.a. = not available

PDU facility where at the operating temperature the iron suffered a thermal expansion. For safety, the operation could not be completely conducted. The use of ordinary iron-based material (seamless pipe and esser sheet) have caused the reactor walls both in the riser and gasifier were abraded to form iron flakes. These iron flakes caused blocking during the operations, so that the sand could not be smoothly and well-circulated. To overcome this problem, it is necessary to modify the PDU facility and select the suitable materials in order to improve the performance of the equipment and to ensure the safety operations. One of the solutions is to replace the ordinary iron-based material with a stainless steel and/or refractory material.

CONCLUSIONS

Puslitbang *tek*MIRA has successfully developed a PDU allothermal gasification facility using a dual fluidized bed technology with the capacity of 5 kg/h. The results of the test of the PDU facility was rather good shown by two parameters, i.e. pressure loop and syngas composition. Pressure loop indicated the stable sand circulation condition. Consequently, the heat transfer released from char combustion to supply gasification process could be well-accomplished. In addition, the low N_2 composition of syngas showed that there was no leakage of air from char combustion in the riser, as a result the H_2 composition and the ratio of H_2 to CO were high.

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