PRODUCTION OF SYNTHESIS GAS FROM INDONESIAN LOW RANK COALS USING FLUIDIZED BED GASIFICATION REACTOR

SLAMET SUPRAPTO AND NURHADI
R & D Centre for Mineral and Coal Technology
Jalan Jenderal Sudirman 623 Bandung 40211, Ph. (022) 6030483, Fax. (022) 6003373

Received : 02 April 2007, first revision : 08 May 2007, second revision : 10 May 2007, accepted : 12 June 2007

ABSTRACT

In relation to the objective of securing energy and raw material supplies for industries and increasing of low rank coal utilization; research on the production of synthesis gas from Indonesian coal has been carried out. Low rank coal samples and a fluidized bed reactor which was equipped with gas purification system have been used. The coal samples used were Adaro coal (sub bituminous), Mulia and Gunung Bayan (lignitic coals). Gasifying agent was also varied and consisted of oxygen, oxygen/ steam mixture and steam. Stoichiometric ratio of oxygen/carbon was kept at one half and oxygen/ steam ratio was one. The gasification temperature was kept constant at 900ºC. The composition of gas products were analyzed using a gas chromatograph with molsieve and porapak columns. The results showed that there was a good correlation between gasifying agent, coal used, quality and quantity of synthesis gas.

Keywords: synthesis gas, coal gasification, low rank coal, fluidized bed

1. INTRODUCTION

Coal is considered as one of the potential energy sources which is expected to substitute oil as the source of energy and raw material for chemical industries in Indonesia. At present, coal resources in Indonesia are estimated to reach 61 billion tons, more than 80% are low rank coals. The low rank coal is mostly not yet exploited due to the high moisture content and low calorific value. This non-exportable coal is better to be used locally for electricity, upgraded into good quality coal or converted into other valuable products. In anticipating this problem, intensive research and development program has to be carried out with sensible objectives, among others is to secure its future energy and raw material supplies for industries in order to preserve the oil reserves.

The production gas from coal known as town gas was carried out in Indonesia until early 1970's using special imported high rank coal, i.e., coking coal (Suprapto, 2000). Gasification of Indonesian non coking coal using fixed bed technology has been started since 1995 for generation of producer gas (Suprapto, 1995). Coal gasifier for small and medium scale industries has been developed and it has been used for tea drying successfully (Suprapto, 2002).

In line with government program to develop clean coal technology and to anticipate the more stringent environmental regulation, conversion of coal into gaseous product is an alternative utilization of Indonesian low rank coal. The gas resulted from coal gasification can be utilized as fuel and raw material for chemical industries as well as for synthetic oil.

In relation to the objective of securing energy and raw material supplies for industries, research on coal gasification of Indonesian low rank coal for generation of synthesis gas needs to be carried out. The experiment was based on the use of Indonesia low rank coal and a fluidized bed reactor.

Content

2. GASES FROM COAL GASIFICATION

Gases produced from coal gasification depend on type coal gasification and gasifying agents. Coal gasification can be defined as the conversion of coal into gaseous products, especially carbon monoxide (CO) and hydrogen (H_2) either without or using reactant or gasifying agent (air, oxygen, steam, CO or mixture of these) in a reactor. If the gasification is carried out directly in-situ, in a coal seam, the process is known as underground coal gasification. CO and H_2 can be processed further into methane which is known as synthetic natural gas (SNG). Coal resulted from gasification process is different with Coal Bed Methane (CBM) since CBM is methane gas trapped which was already exist in the coal seam during the coalification process (Caltex, 1998).

In practice, classification of gas produced from coal gasification is based on the calorific value of gas and the gasifying agent used. Three general types of gas from coal are known, i.e., low, medium and high Btu gases. In general, low Btu gas is gases with calorific value less than 200 Btu/ft^3. Medium Btu gas is gases with calorific value between 200-400 Btu/ft^3. While high Btu gas is a gas with calorific value between 400–1000 Btu/ft^3 (Nowacki, 1981).

Town gas which is normally resulted from carbonization process contains mainly of CH_4 (methane) and H_2. It is usually distributed and sold at a calorific value of 500 Btu/ft^3. Producer gas is coal gas resulted from partial combustion of coal using air as the gasifying agent. It consists mainly of CO and N_2 with small proportion of H_2, CH_4 and CO_2. The calorific value of producer gas is about 145-164 Btu/ft^3. Water gas is obtained from gasification of coal using mixture of air and steam as the gasifying agent. The addition of steam will increase the content of CO and H_2 because steam will react with carbon to become CO and H_2. But, because of using air, the nitrogen content of water gas is still high and the calorific value of water gas is still less than 200 Btu/ft^3.

Lurgi gas is coal gas resulted from the gasification of coal using mixture of oxygen and steam. It contains more combustible gases (carbon monoxide, hydrogen, methane etc.) and lower nitrogen compared with those of producer gas and water gas. The calorific value of Lurgi gas is about 400 Btu/ft^3. If Lurgi gas is purified by removing the impurities and increasing CO and H_2, the gas is called synthesis gas (syngas). Synthesis gas can be processed further through methanation reaction to become synthetic or substitute natural gas (SNG) with the calorific value of about 1000 Btu/ft^3 (Francis, 1965; Nowacki, 1981).

Reactor type of coal gasification is mainly classified according to contacting mode of coal particle with gasifying agents. Four main types of reactor generally used for coal gasification consist of fixed bed, fluidized bed, entrained bed and molten bath bed systems (Elliot, 1981; Ward, 1984).

Fluidized bed reactor operates on the principle of suspending fine coal particles (less than 5 mm), in turbulent motion and a high velocity of upward flow of gasifying agents. The turbulent environment provides excellent gas-solid contact, which rapidly heats entering gasifying agents to the bed temperature and facilitates their intimate mixing and operation.

3. METHODOLOGY

3.1. Apparatus

Figure 1 shows the schematic diagram of the experimental system of the synthesis gas production from Indonesian low rank coals using fluidized bed technology. It consisted of a bubbling fluidized bed reactor, as well as coal feeding, reactant feeding and gas purification units. The reactor was made of a silica column with the capacity of about 5 g/minute. It was wound by electric heaters for heating-up to the gasification temperature. The coal feeding unit consisted of a screw feeder and mass flow controller. It was also equipped with a nitrogen flow system for pushing the coal into the reactor. The reactant feeding unit consisted of oxygen and steam flowing systems. The oxygen flowing system was equipped with a mass flow to measure the flow rate. The steam flowing system was equipped with a small electric boiler to convert water into steam. The gas purification system consisted of a cyclone to catch char and tar separators unit. The tar separator unit consisted of two tar coolers with their tar collectors and one solvent extraction unit.

3.2. Gas Sampling and Analysis

The gas products were sampled manually after steady operation in the period of fifteen minutes using sampling bags. The gas composition consisted of CO, H_2, CH_4, C_2H_2 (acetylene), C_2H_4

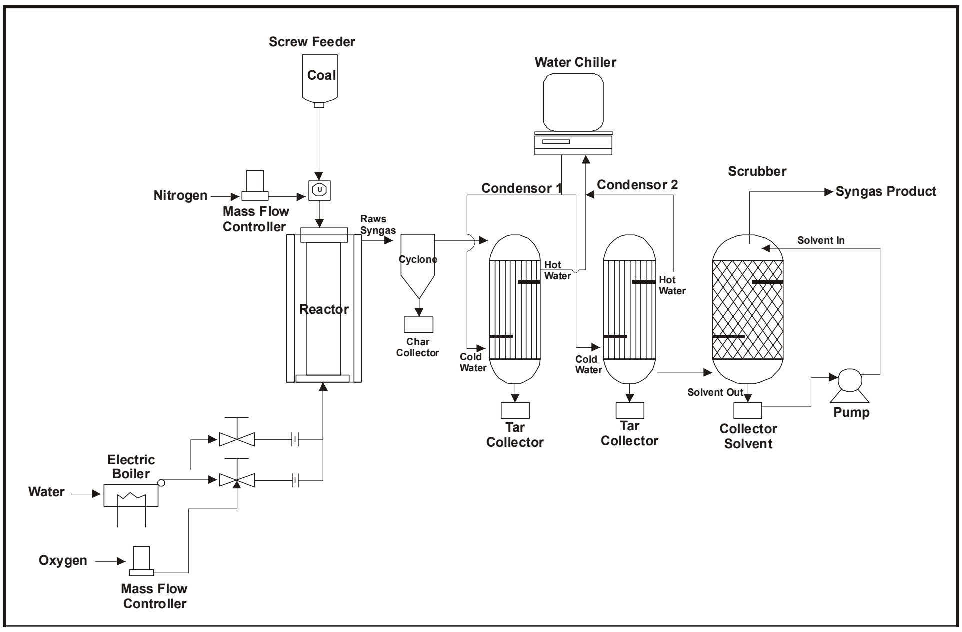


Figure 1. Schematic diagram of the experimental system

(ethylene), C_2H_6 (ethane), CO_2 and O_2 was analyzed using a gas chromatograph equipped with molsieve and porapak-Q columns. Apart from the composition of gas product, the gas volume was also measured. The calorific values of gases were calculated from composition of their flammable components (Francis, 1965).

3.3. Coal Used

Three low rank coal samples (lignite and sub bituminous coal) from South Kalimantan were used for the experiments. They were crushed into -48+65 mesh size and dried at 100ºC before fed into the reactor. Analysis data of the coal samples are shown in Table 1. Mulia (Arutmin) coal is lignite while Adaro and Gunung Bayan coals are sub bituminous in rank. Mulia coal contained higher inherent moisture and oxygen contents but with lower calorific value, volatile matter and carbon contents. Conversely, Adaro and Gunung Bayan coals contained lower inherent moisture and oxygen but with higher calorific value, volatile matter and carbon contents compared to those of Mulia coal.

Table 1. Analysis data of coal samples

Parameter	Adaro		Mulia		G. Bayan	
	adb	db	adb	db	adb	db
Total moisture, %. a.r.	n a	-	32.28	-	33.75	-
Inherent moisture, %	17.73	-	29.47	-	15.35	-
Ash, %	0.83	1.01	0.98	1.39	4.42	5.22
Volatile matter, %	40.07	48.71	37.80	53.59	40.68	48.06
Fixed carbon, %	41.37	50.28	31.75	45.02	39.55	46.72
Calorific value, kal/g	5,752	6,992	4,873	6,909	5,431	6,416
Sulphur, %	0.11	0.13	0.17	0.24	0.14	0.17
Carbon, %	59.91	72.82	50.69	71.87	57.55	67.98
* Hydrogen, %	4.36	5.30	3.33	4.72	4.35	5.14
Nitrogen, %	1.00	1.22	0.49	0.69	0.77	0.91
* Oxygen, %	16.06	19.52	14.87	21.09	17.42	20.58

Note : adb: air dried basis; db: dry basis; ar : as received; na : not available
** not including H and O of moisture*

Content

3.4. Experimental Procedures

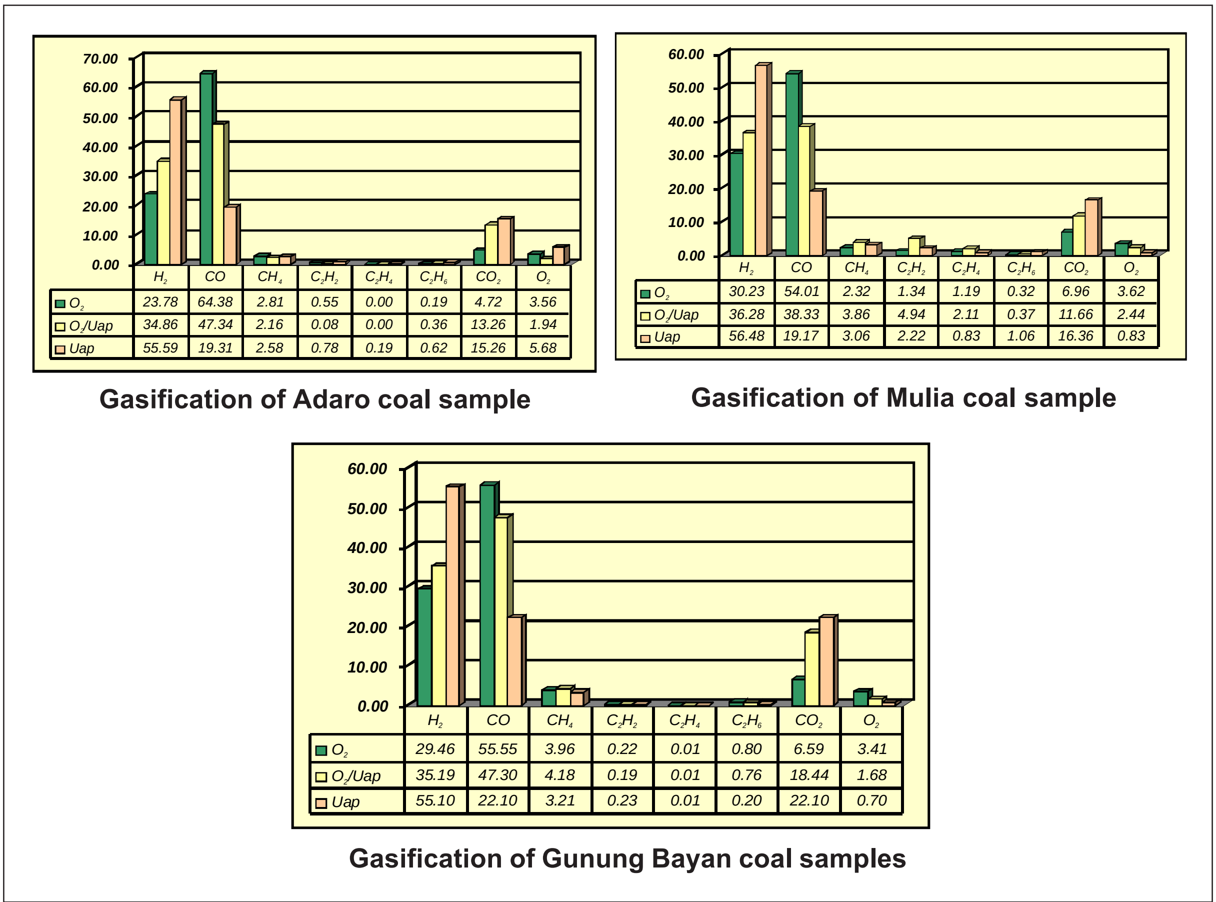
Silica sand particles used as bed materials were initially charged into the reactor and followed by injection of nitrogen. The reactor was preheated to approximately 900ºC using an electric heater. Coal and gasifying agent were then fed into the bed. The flow rate of reactant used for gasification was based on the stoichiometric calculation of oxygen needed for coal combustion. In this case, the amount of oxygen molecule needed for gasification was assumed to be about one half that of needed for combustion. While the molecular ratio between oxygen and steam was made one. After steady condition, the gasification process was continued at least for one hour operation. Beside coal, other variable used in the experiment was reactants which consisted of oxygen, steam and mixture of oxygen and steam.

4. RESULTS AND DISCUSSION

Composition of synthesis gas products resulted from different coal samples and gasifying agents is shown in Appendix 1.

4.1. Effect of Gasifying Agents on the Gasification Products

Figure 2 shows the effect of gasifying agents on the composition of gas produced. Composition of synthesis gas tended to depend on the gasifying agent used. Oxygen blown gasification resulted in synthesis gas with the highest content of CO i.e. up to 64.38%, but with low content of H_2 i.e. 23.78%. Conversely, steam blown gasification resulted in the highest content of H_2 i.e. up to 55.59% and the lowest of CO i.e. 19.31%. While gasification using oxygen/steam mixture resulted in gas



	H_2	CO	CH_4	C_2H_2	C_2H_4	C_2H_6	CO_2	O_2
O_2	23.78	64.38	2.81	0.55	0.00	0.19	4.72	3.56
O_2/Uap	34.86	47.34	2.16	0.08	0.00	0.36	13.26	1.94
Uap	55.59	19.31	2.58	0.78	0.19	0.62	15.26	5.68

Gasification of Adaro coal sample

	H_2	CO	CH_4	C_2H_2	C_2H_4	C_2H_6	CO_2	O_2
O_2	30.23	54.01	2.32	1.34	1.19	0.32	6.96	3.62
O_2/Uap	36.28	38.33	3.86	4.94	2.11	0.37	11.66	2.44
Uap	56.48	19.17	3.06	2.22	0.83	1.06	16.36	0.83

Gasification of Mulia coal sample

	H_2	CO	CH_4	C_2H_2	C_2H_4	C_2H_6	CO_2	O_2
O_2	29.46	55.55	3.96	0.22	0.01	0.80	6.59	3.41
O_2/Uap	35.19	47.30	4.18	0.19	0.01	0.76	18.44	1.68
Uap	55.10	22.10	3.21	0.23	0.01	0.20	22.10	0.70

Gasification of Gunung Bayan coal samples

Figure 2. The effect of gasifying agent on gas composition

Content

with CO and H_2 contents in between the two former results.

Principally, oxygen blown gasification is a partial combustion of coal in which carbon reacts with oxygen to form CO. While in steam blown gasification there is a shift reaction between steam and hydrocarbons and also char from coal to form mostly hydrogen. Reaction processes of oxygen blown and steam blown gasifications are as follows (Ward, 1984) :

$C + ½ O_2 \rightarrow CO$ (partial combustion)
$C + H_2O \rightarrow CO + H_2$ (shift reaction)

Figure 3 shows the effect of gasifying agents on calorific value of gas produced. Oxygen blown gasification resulted in gases of the highest calorific value i.e. 2,875 Cal/m^3 in average and steam blown gasification produced gases of the lowest calorific value i.e. 2,482 kcal/m^3 in average. While gasification using oxygen/steam mixture produced gases of calorific value in between the two former results i.e. 2,480 kcal/m^3 in average. This result can be explained that gases from oxygen blown gasification contained higher CO. In this case, the calorific value of CO is higher than that of H_2

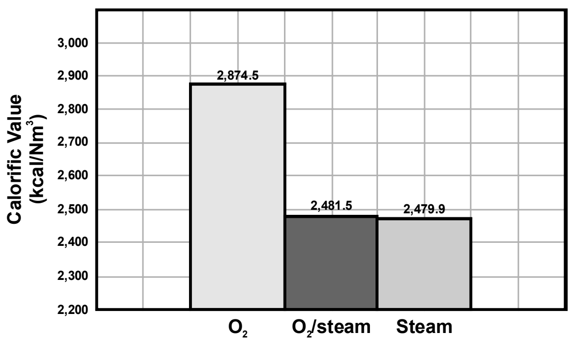


Figure 3. The calorific value of gases produced by gasification using different gasifying agents

Figure 4 shows the effect of gasifying agents on the volumes of gases produced. The volumes of gases produced by oxygen/steam blown gasification were the highest compared to those of oxygen blown and steam blown gasification, i.e., 1,731

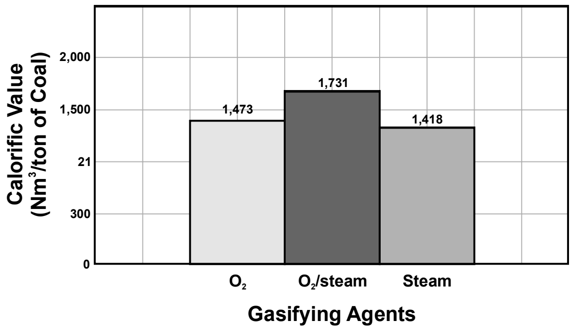


Figure 4. The volume of gases produced from gasification using different gasifying agents

m^3/ton dry coal in average. While the volumes of gases produced from oxygen blown and steam blown were similar i.e. 1,473 m^3/ton dry coal and 1,418 m^3/ton dry coal in average.

4.2. Effect of Coal Samples on the Gasification Products

Figure 5 shows the effect of different coal samples on the composition of gas produced. The effect of different coal samples depended also on the gasifying agent used. Adaro coal produced high CO content and low H_2 content from oxygen blown gasification. Conversely, Mulia coal resulted in low CO content from oxygen/steam blown gasification. While steam blown gasification using different coal samples produced similar CO and H_2 contents. These results can be explained that Adaro coal sample which was of higher rank coal (sub bituminous coal) contained high percentage of carbon, while Mulia coal sample which was of lower rank coal (lignite) contained low carbon (Table 1). The partial combustion of carbon produced the highest CO for Adaro coal sample and the lowest CO for Mulia coal sample.

Figure 6 shows the effect of different coal samples on the calorific value of gas produced. Adaro coal sample produced the higher average calorific value compared with those of resulted from Mulia and Gunung Bayan coal samples. Similarly, the vo- lume of synthesis gas produced by Adaro coal sample was also the highest compared with those of resulted from the other two coal samples lignite (Figure 7).

Content

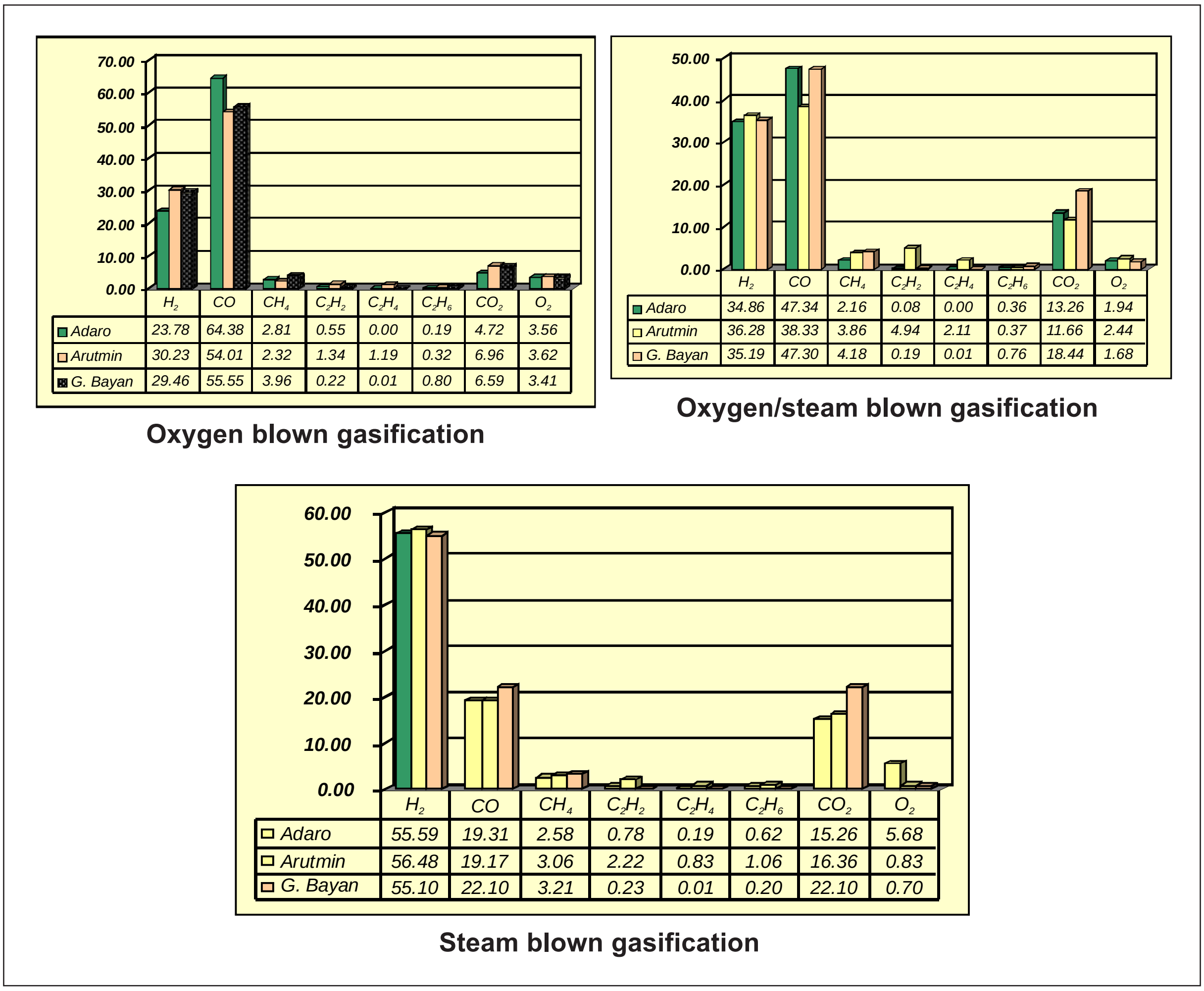


Figure 5. The effect of different coal samples on gas composition

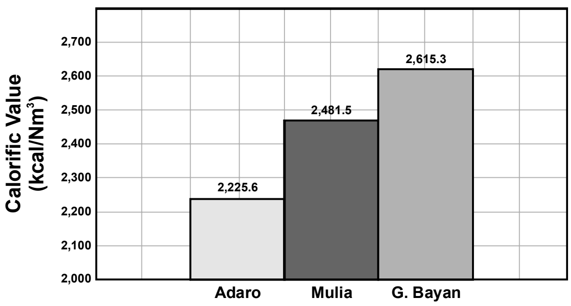


Figure 6. Calorific value of gas produced from different coal samples

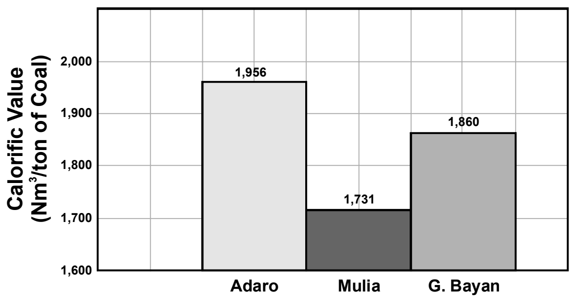


Figure 7. Volume of gas produced from different coal samples

Content

5. CONCLUSION

Experiment on the production of synthesis gas from Indonesian low rank coal using fluidized reactor has been carried out successfully. There was good correlation between gasifying agent and coal used and quality and quantity of synthesis gas produced.

Oxygen blown gasification produced synthesis gas with high CO content and low H_2 content. Conversely, steam blown gasification resulted in high H_2 content and low CO content. While gasification using oxygen/steam mixture produced gas with CO and H_2 contents in between the two former results.

Oxygen blown gasification produced gases with high calorific value and steam blown ga- sification produced gases with low calorific value. While gasification using oxygen/steam mixture produced gases of calorific value in between the two former results.

Volume of synthesis gas produced from oxygen/ steam blown gasification was higher compared to those of oxygen blown and steam blown gasification.

Effect of different coal samples on the gas quality depended also on the gasifying agent used. Adaro coal produced high CO and low H_2 contents from oxygen blown gasification. Conversely, Mulia coal resulted in low CO content from oxygen/steam blown gasification. The contents of CO and H_2 resulted in steam blown gasification of different coal samples were similar.

Adaro coal sample produced synthesis gas with high calorific value and volume compared with those of resulted from Mulia and Gunung Bayan coal samples.

REFERENCES

Caltex, 1998. *The potential of coal bed methane in Indonesia*. PT Caltex Pacific Indonesia, Jakarta.

Elliot, M.A. (ed.), 1981. *Chemistry of coal utilization*. Second Suppl. Vol., John Wiley & Sons, New York.

Francis, W., 1965. *Fuels and Fuel Technology*. Vol II, Section C: Gaseous Fuels. Pergamon Press, Oxford.

Nowacki, P. (ed.) 1981. *Coal gasification process*. Noyes Data Corporation, New Jersey.

Suprapto, S., Rochman, T. and Basyuni, Y., 1995. Gasifikasi batubara peringkat rendah dengan pereaksi udara. *Prosiding Seminar Ilmiah Hasil Penelitian dan Pengembangan Bidang Fisika Terapan*, Bandung.

Suprapto, S., 2000. Gasification Processes with Respect to Characteristics of Indonesian Coal. *Indonesian Mining Journal*, vol. 6, No. 2.

Suprapto, S., Heryadi, D. dan Basyuni, Y. 2002. Pemanfaaatan Batubara Untuk Pengeringan Teh Hijau Menggunakan Lemari Pengering Sistem Berkala dan Reaktor Gasifikasi Unggun Tetap. *Makalah Ini Disampaikan Pada Seminar Nasional Kimia II – Jaringan Kerjasama Kimia Indonesia*, Jogyakarta.

Ward, C.R. (ed.), 1984. *Coal geology and coal technology*. Blacwell Scientific Publications, Melbourne.

Appendix 1. Composition of syngas result from coal gasification

Coal	Gasifying agent	H_2 %	CO %	CH_4 %	C_2H_2 %	C_2H_4 %	C_2H_6 %	CO_2 %	O_2 %
Adaro	O_2	23.78	64.38	2.81	0.55	0.00	0.19	4.72	3.56
	O_2/Steam	34.86	47.34	2.16	0.08	0.00	0.36	13.26	1.94
	Steam	55.59	19.31	2.58	0.78	0.19	0.62	15.26	5.68
Mulia	O_2	30.23	54.01	2.32	1.34	1.19	0.32	6.96	3.62
	O_2/Steam	36.28	38.33	3.86	4.94	2.11	0.37	11.66	2.44
	Steam	56.48	19.17	3.06	2.22	0.83	1.06	16.36	0.83
G. Bayan	O_2	29.46	55.55	3.96	0.22	0.01	0.80	6.59	3.41
	O_2/Steam	35.19	47.30	4.18	0.19	0.01	0.76	18.44	1.68
	Steam	55.10	22.1	3.21	0.23	0.01	0.20	22.10	0.70

Content