Soetjijo H. Jurnal Riset Geologi dan Pertambangan Jilid 18 No.1 (2008) 14-22

Benefit of Channel Availability In An Underground Coal Gasification Laboratory Scale

Harijanto Soetjijo[a]

[a]Pusat Penelitian Geoteknologi, LIPI, Jl. Sangkuriang Bandung 40135

ABSTRAK *Keunggulan dari keberadaan alur gasifikasi pada percobaan gasifikasi batubara bawah tanah diselidiki di laboratorium. Percobaan dilakukan dengan menggunakan sebuah reaktor simulasi berbentuk persegi panjang yang terbuat dari besi. Dalam studi ini ada dua percobaan yang dilakukan yaitu: percobaan pertama tanpa adanya alur gasifikasi dan percobaan kedua dengan sebuah alur gasifikasi didalam reaktor. Hasil percobaan menunjukkan bahwa jumlah gas* CO_2 *adalah dalam kisaran (4,6-11,4)% dan (11,6-14,4)%; gas CO dalam kisaran (0,3-4,0)% dan (1,2-6,8)%; gas* H_2 *dalam kisaran (0,1-2,5)% dan (1,6-3,2)%; gas* C_3H_8 *dalam kisaran (0,0-0,6)% dan (0,2-0,9)%; gas* CH_4 *dalam kisaran (0,0-2,2)% dan (0,4-3,0)%, gas* C_nH_m *adalah dalam kisaran (0,0-0,0)% dan (0,0-0,4)% untuk percobaan pertama dan kedua berturut-turut. Nilai kalori gas adalah dalam kisaran (81-343)kcal/*m^3 *dan (263-516)kcal/*m^3 *berturut-turut. Kisaran dari pengembangan temperatur pada saat proses gasifikasi berjalan menunjukkan bahwa pada percobaan pertama, kisaran temperatur gasifikasi* T_1 *pada adalah (335-565)*^oC*; dan* T_2 *adalah dalam kisaran (110-240)*^oC*. Dilain pihak,* T_1 *untuk percobaan kedua adalah dalam kisaran (550-705)*^oC *dan* T_2 *dalam kisaran (160-628)*^oC*. Selain itu pada percobaan pertama, pola perubahan temperatur* T_1 *dan* T_2 *mempunyai kecenderungan menurun, sedangkan pada percobaan kedua, pola temperatur* T_1 *dan* T_2 *tersebut mempunyai kecenderungan meninggi seiring dengan jalannya proses gasifikasi. Hal ini dapat disimpulkan bahwa adanya alur gasifikasi pada percobaan kedua memungkinkan reaksi-reaksi gasifikasi berjalan lebih efisien dibandingkan dengan reaksi-reaksi yang terjadi pada percobaan pertama tanpa alur didalamnya.*

Kata Kunci : Gasifikasi bawah tanah, batubara, alur, reaktor, komposisi gas

ABSTRACT The benefit of gasification channel availability in an underground coal gasification experiment is investigated in laboratory. The experiment is conducted using a simulation rectangular reactor made of steel. There are two experiments conducted in this study: the first experiment is without gasification channel and the second experiment with a gasification channel inside the reactor. The result of the experiments shows that the amount of CO_2 gas is in the range of (4,6-11,4)% and (11,6-14,4)%; CO gas is in the range of (0,3-4,0)% and (1,2-6,8)%; H_2 gas is in the range of (0,1-2,5)% and (1,6-3,2)%; C_3H_8 gas is in the range of (0,0-0,6)% and (0,2-0,9)%; CH_4 gas in the range of (0,0-2,2)% and (0,4-3,0)%, C_nH_m gas in the range of (0,0-0,0)% and (0,0-0,4)% for the first and the second experiment respectively. The caloric value of gas is in the range of (81-343)kcal/m^3 and (263-516)kcal/m^3 respectively. The range of temperature development during the gasification process shows that: in the first experiment, the range of gasification temperature T_1 is (335-565)^oC; and T_2 is in the range of (110-240)^oC. On the other hand, T_1 from the second experiment is in the range of (550-705)^oC and T_2 is in the range of (160-628)^oC. Besides that in the first experiment, the pattern of T_1 dan T_2 changing has a decreasing tendency, while in the second experiment, it has an increasing tendency in relation with the progress of gasification process. It can be concluded that the availability of gasification channel in the second experiment allows the gasification reactions occur more efficiently compared with the reactions in the first experiment without the channel inside.

Key word : Underground gasification, coal, channel, reactor, gas composition

INTRODUCTION

Underground coal gasification is not a new idea, it was first suggested by Siemens in 1868 for the gasification of coal left in place after mining. Underground coal gasification is a method of converting unworked coal, deep underground, into a combustible gas, which can be used for industrial heating, power generation or the manufacture of hydrogen, synthetic natural gas or other chemicals.

Basically, this method allows us to eliminate the need for mining especially for the coal which is considered uneconomical to mine, due to several reasons for example the coal seam which locates very deep underground. Edgar (1974) mentioned that this underground coal gasification method was the most economical method to convert the solid coal to gas. Besides that, this method is able to reduce the risk of mining and minimize the environmental destruction related with the mining activities (Schrider & Whieldon, 1977).

The basic concept of underground coal gasification is illustrated in Figure 1. Two boreholes, or wells, are drilled to the bottom of the coal seam to be gasified. Normally the natural permeability of the coal bed is not high enough nor the fissures large enough to permit gas percolation through the seam, so it is necessary to enhance the permeability. This is called "linking" of the wells or in other word it can be mentioned as the gasification channel forming, in which narrow linear channel of high permeablity are formed without increasing the permeablity of the bulk of the coal seam. There are three parameters affects the underground gasification process. The first parameter is the geological parameter such as coal seam thickness, type of overburden; country rocks; and water table. The second group of parameters is the characteristics of coal such as moisture and ash contents; caking ability etc. The third group is the operasional parameters of gasification such as airflow rate; gasification channel; oxygen rate, pressure, the length of gasification zone etc. The knowledge and understanding of those parameters are very important and very helpful in planning the equipments related with the operation and interpretation of the result of underground coal gasification.The geological parameters and characteristics of coal are the most important and closely related. The operasional parameters are used to eliminate or at least to reduce the negative effect of geological parameter and characteristics of coal in this underground coal gasification. The effective combination of these parameters can support the successive progress of an underground coal gasification either from quantity or quality of gas product or from the efficiency point of view of this gasification process (Gunn, 1978).

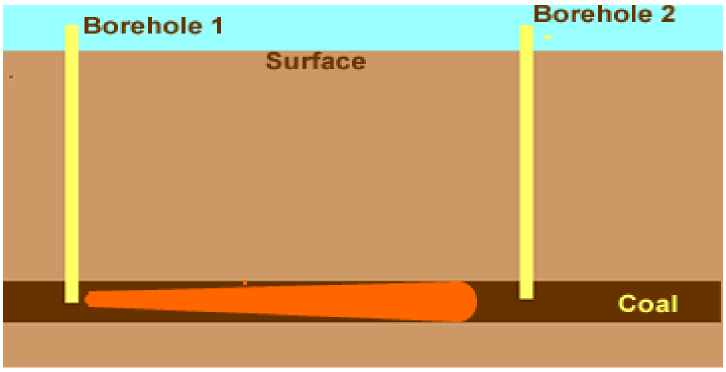

Figure 1. Basic concept of an undergrund coal gasification.

In Indonesia, there are several location which have coal seams considered uneconomical to mine, for example in Bayah, South of Banten; Sawahlunto, West Sumatra. To anticipate the increasing need of energy in the future, a study to provide a clean and covenient source of energy from coal seams where tradional mining methods are either impossible or uneconomical is proposed in Research Centre of Geotechnology. An experimental study in laboratory using a simulation underground coal gasification reactor is conducted. According to Thomas (1978) and Thorness G.B., et al. (1978), a simulation reactor has to be designed to cover as many as all the parameters which are considered will affect the gasification process.

In this paper, the result of an experiment of underground coal gasification using a simulation reactor and the effect of the availability of a gasification channel to the gas composition and process will be discussed.

MATERIAL AND METHODS

Underground gasification reactor

In this study, a simulation reactor which designed to cover almost all the conditions of underground coal gasification is used. This rectangular reactor is made from steel plate with 2 mm thickness. The length of the reactor is 80 cm, width is 30 cm and height is 20 cm. The reactor has an initial iginition hole; air input hole; and a gas output hole. The reactor is completed with two thermocouples, located 25 cm from its edges. The reactor is put in a wood box (120 X 80 X 50 cm) and covered with clay and soil to prevent heat loss during the gasification process. There is a temporary plate made of tabular pipe steel which can be used to separate the room inside the reactor. This plate is put about 4 cm from the base of reactor and arranged in a manner so that there is a channel in the lower part of reactor. This separator is used to form a gasification channel inside the reactor. This separator plate is used for the second experiment but the plate is not used in the first experiment. Figure 2 represents the basic design of the reactor.

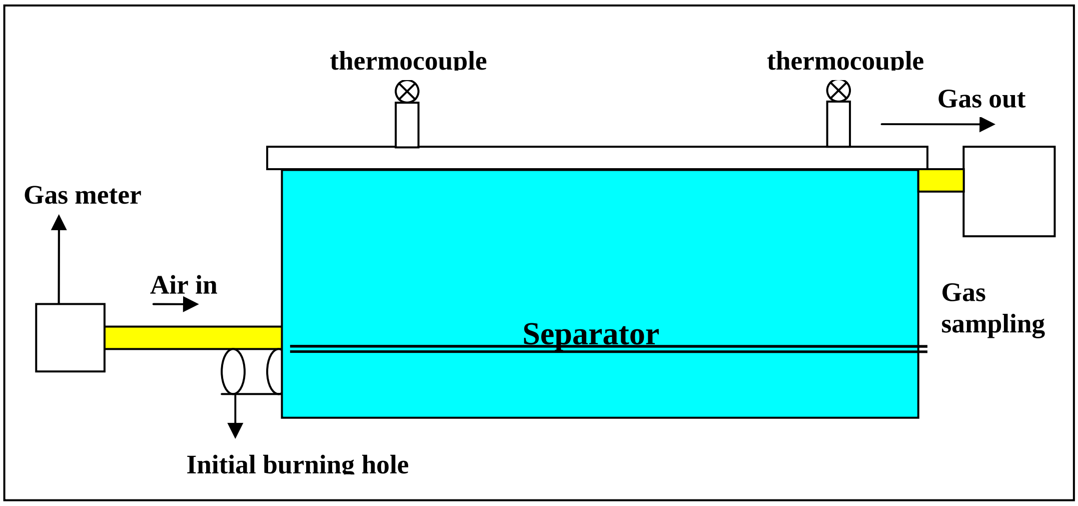

Figure 2: The basic design of simulation underground coal gasification reactor.

Compressor

Reactor is completed with a compressor which supplies air input to reactor during the process.

Gas meter

A gas meter is used to measure the volume of air input flowing to the reactor during the experiment.

Coal

Coal used in the experiment is obtained from Widodaren, Rembang, Middle of Java. The size of coal used in the process is –3 cm. The composition of Widodaren coal is as followed: Moisture content = 10,08%; ash content = 3,83%; volatile matter content = 31,51% dan fixed carbon content = 54,48%.

Procedure

Coal with size –3 cm diameter is filled into the reactor. The reactor is then put in a wooden box and covered with clay and soil. The gasification is started with the initial ignition using a burner. The initial ignition is set for two hours and after the coal starts to burn itself, the air from the compressor is blowed to the reactor through the air input hole. Air flow from the compressor is arranged using a gas meter. In this experiment, the air flow is set at 70 litres per minute.

There are two experiment conducted.

In the first experiment, coal fills all part of reactor so that there is no gasification channel inside. The burning of coal will start from the bottom of the reactor from where the gasification occurs and the propagation of gasification runs freely. Consequently the ash will set down naturally so that some of coal remains unburn due to the ash covering the coal.

On the other hand, in the second experiment the coal only fills the upper part of reactor because the separator is set in the reactor so that there is a empty room (channel) in the bottom of reactor. Due to this arrangement the initial burning starts on the layer of coal laid about 4 cm from the bottom of reactor. As the gasification is in progress and ash as the byproduct of the process will set down into this empty part. The gasification occurs without any interference and no unburned coal due to the ash falling down covering the coal as happened in the first experiment without gasification channel inside.

Length of experiment

The gasification experiment is conducted for 16 hours totally. The initial ignition is 2 hours, and the gasification runs for 14 hours.

Gas sampling

Gas from the experiment is sampled using a gas sampling tube (length is 30 cm and diameter is 5 cm) made from glass. The gas sampling is done using the gravitation method. The gas sampling is done every hour during the course of the gasification process so that there is 14 gas samples for one experiment in each reactor.

Gas analysis

Gas analysis is conducted using Orsat equipment. The gas component analyzed is as followed: CO_2; C_nH_m; O_2; CO; H_2: C_3H_8; CH_4 dan N_2. The calorific value of gas is calculated based on the procentage of C_nH_m; CO; H_2: C_3H_8 dan CH_4 content.

RESULTS AND DISCUSSION

There are two experiments conducted in this study. The result obtains from the first experiment is summarized in Table 1. The result of the second experiment conducted with a gasification channel inside is summarized in Table 2.

The result of the first gasification experiment conducted using the reactor without gasification channel inside shows that (see Table 1):

The content of gas CO_2 is (4,6-11,4)%; gas C_nH_m is (0,0-0,0)%; gas O_2 is (4,6-11,4)%; gas CO is (0,3-4,0)%; gas H_2 is (0,1-2,5)%; gas C_3H_8 is (0,0-0,6)%; gas CH_4 is (0,0-2,2)%; gas N_2 is (76,2-81,0)%.
The calorific value of gas is (81-343) kcal/m^3.
The range of temperature during the experiment is: T_1 = (335-565)^oC; and T_2 = (110-240)^oC.

Tabel 1. The result of underground coal gasification without channel inside.

No exp	Gas composition (%) CO_2	C_nH_m	O_2	CO	H_2	C_3H_8	CH_4	N_2	Calorific value kcal/m^3	Vol. Air input l/m	T_1 ^oC	T_2 ^oC
1	10,8	0,0	6,0	4,0	0,9	0,0	0,7	77,6	215	70	565	240
2	11,4	0,0	5,4	4,0	0,9	0,1	0,5	77,7	220	70	560	230
3	9,2	0,0	7,8	3,2	0,7	0,1	0,2	78,8	161	70	550	225
4	9,6	0,0	7,8	3,2	0,5	0,1	0,2	78,6	155	70	540	220
5	8,8	0,0	6,0	2,4	0,9	0,1	2,2	79,6	332	70	515	190
6	10,8	0,0	5,2	3,4	0,9	0,1	0,2	79,4	173	70	510	180
7	7,8	0,0	10,4	3,0	0,6	0,0	0,0	78,2	109	70	500	175
8	5,4	0,0	8,6	1,4	0,9	0,5	0,0	80,6	343	70	495	170
9	9,7	0,0	7,1	3,0	0,5	0,1	1,6	79,6	130	70	480	175
10	10,0	0,0	6,4	2,8	0,5	0,1	0,2	80,0	142	70	470	180
11	5,0	0,0	12,8	1,4	0,1	0,1	0,6	80,0	126	70	440	160
12	6,7	0,0	10,7	0,3	2,5	0,6	0,4	78,8	175	70	415	150
13	4,6	0,0	13,1	2,3	0,6	0,2	0,8	78,4	185	70	350	120
14	7,2	0,0	10,6	2,4	3,0	0,1	0,5	76,2	227	70	335	110

On the other hand, the second gasification experiment conducted in the reactor with gasification channel inside shows that (see Table 2):

The content of gas CO_2 is (11,6-14,4)%; gas C_nH_m is (0,0-0,4)%; gas O_2 is (3,2-7,2)%; gas CO is (1,2-6,8)%; gas H_2 is (1,6-3,2)%; gas C_3H_8 is (0,2-0,9)%; gas CH_4 is (0,4-3,0)%; gas N_2 is (73,0-77,6)%.
The calorific value of gas is (263-516)) kcal/m^3.
The range of temperature during the experiment is: T_1 = (550-705)^oC; and T_2 = (160-628)^oC.

Based on these results, it shows that the amount of gases produces from both of the experiments is different. The amount of gases CO_2; C_nH_m; CO; H_2; C_3H_8 dan CH_4 produces from the second experiment is higher than the gases obtained from the first experiment. Consequently, the quality of gas produces from the first experiment is lower compares the quality of gas produces from the second experiment as shown by the calorific value of the gas. Figure 3 shows the calorific value of the gas produces from the experiments.

Tabel 2. The result of underground coal gasification with channel inside.

No Exp	Gas composition (%) CO_2	C_nH_m	O_2	CO	H_2	C_3H_8	CH_4	N_2	Calorific value kcal/m^3	Vol. Air input l/m	T_1 °C	T_2 °C
1	12,8	0,0	4,4	1,4	1,8	0,6	0,4	77,6	263	70	550	160
2	14,0	0,2	4,2	1,2	2,4	0,6	1,8	75,6	400	70	560	175
3	13,2	0,0	6,2	1,4	2,8	0,4	2,0	74,0	391	70	600	200
4	14,1	0,2	4,1	1,8	1,9	0,5	2,4	75,0	435	70	620	230
5	11,7	0,1	7,2	1,6	2,0	0,4	2,0	75,0	373	70	640	260
6	11,8	0,2	6,0	1,8	3,0	0,5	1,7	75,0	403	70	668	335
7	12,0	0,0	6,0	2,7	2,3	0,8	1,6	74,6	467	70	680	350
8	11,8	0,0	6,4	2,6	1,8	0,2	2,2	75,0	369	70	705	395
9	11,6	0,2	6,0	6,8	1,8	0,4	3,0	74,2	492	70	695	430
10	12,8	0,2	5,0	3,0	3,2	0,4	2,4	73,0	484	70	682	515
11	13,4	0,4	3,6	3,0	2,6	0,8	1,8	74,4	502	70	678	540
12	14,4	0,0	3,2	3,4	3,0	0,6	2,2	73,2	516	70	672	585
13	13,8	0,2	3,2	3,4	1,9	0,9	1,6	75,0	497	70	665	605
14	13,6	0,0	4,0	3,4	1,6	0,2	1,2	76,0	296	70	655	628

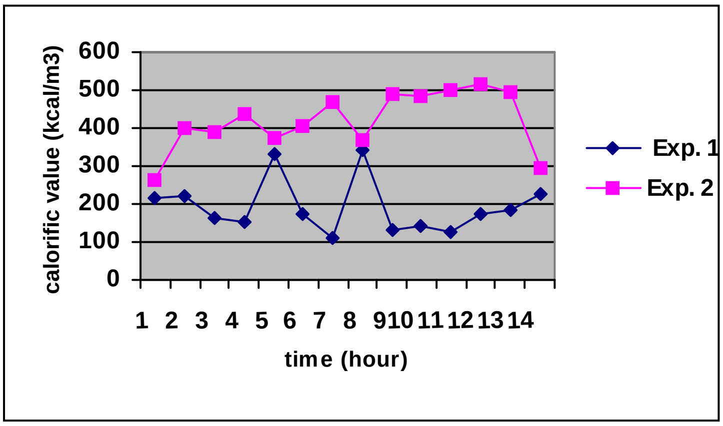

Figure 3: The calorific value of gas obtained from the first and second experiment.

Based on these results, it can be said that the gasification process occurs in the second experiment is better compared the gasification process occurs in the first experiment. This relates with the actual conditions happened during the course of the gasification. Pyrolysis and gasification of coal occurs in the first experiment is running in lower degree due to the unavailability of gasification channel inside the reactor. In the first experiment, ash produces after the gasification took place covers the unburn coal which lays in the bottom of reactor. Ash remaining and unburn coal will affect and participate the gasification reactions. If it enters downstream after the reactions, there is a loss in sensible heat and the temperature in reactor is reduced. This reduction of temperature has the negative effect as shown by the amount and quality of gases produces. It is quite different with the conditions occurs in the second experiment conducted in the reactor which has a gasification channel inside. No ash covers the coal so that there is no inhibition in gasification progress so that most of the coal burns completely and gasification is propagates in the right manner.

This condition is also supported by temperature observation obtains from both experiments. The gasification temperature in the first experiment is as follows: T_1 is in the range of (335-565)^oC; and T_2 is in the range of (110-240)^oC. On the other hand, temperature in the second experiment is as follows: T_1 is in the range of (550-705)^oC; and T_2 in the range of (160-628)^oC. These data indicate that the temperature T_1 dan T_2 measured from the second experiment is higher than T_1 dan T_2 from the first experiment.

Besides that, the pattern of temperature changing during the course of gasification in the first experiment is quite different with the pattern of temperature changing occurred in the second experiment. Based on the observation of temperature obtains from the first experiment, the pattern of T_1 has a decreasing tendency during the gasification progressing. The same pattern also occurres for T_2 (see Figure 4). On the other hand, the pattern of temperature T_1 and T_2 obtained from the second experiment have a different tendency compared with pattern of T_1 and T_2 from the first experiment. The pattern of T_1 and T_2 in the second experiment has an increasing tendency in relation with the course and time period of the experiment (see Figure 5).

These differences show that the condition occurres in both experiments or reactors are not same. In the first experiment, after the initial coal burning, the gasification occurs in the bottom of reactor and the coal above falls into the void and also the ash due to the gravitation effect. This condition is unfavourable for the process and consequently some part of coal goes unburn, so that there is a heat loss and it affects the gasification temperature. The temperature along the seam is not high enough to maintain the reactions and as the result the progress of the gasification is not optimum.

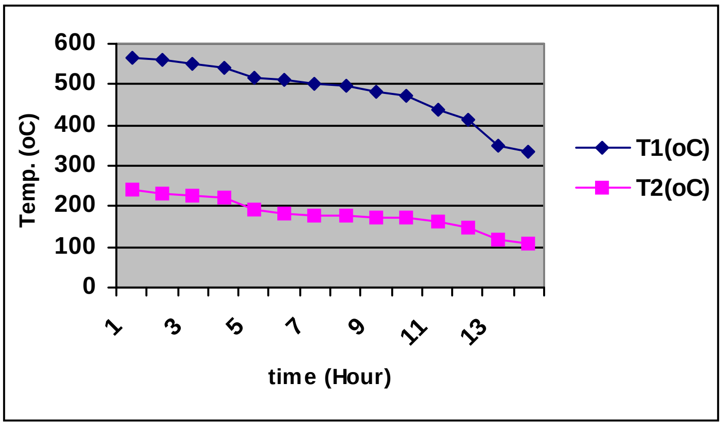

Figure 4: The pattern of temperature obtained from the first experiment (conducted without channel inside the reactor)

However, in the second experiment, due to the availibility of the channel in the bottom of the reactor, the coal burning occures in the right track and ash setlles down in the bottom of reactor without interference the gasification progress. It is supported by Wieber et al.,1978, who mentioned that the gasification process gives a better result if the initial burning coal occurred in the bottom of coal seam. The channel of gasification in the bottom of coal seam allows a better reactions take place and with the channel at the bottom of the seam, the coal initially consumes from the bottom part and progresses to the upper part of coal seam. The combustion which is pushed along the seam and as the void grows, the unburned coal falls into it creating a bed of coal rubble that is relatively reactive because of the large surface area is presents. Dinsmoor et al., 1978, also mentioned that the preparation of a gasification channel is important because the availability of the channel or linking can distinguish the gases produces from the gasification. The channel gasification or the linking is the main element and becomes rate limiting.

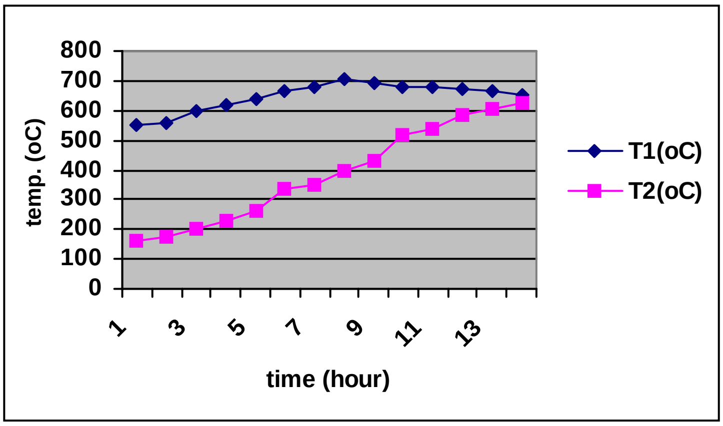

Figure 5: The pattern of temperature obtained from the second experiment (conducted with channel inside the reactor)

In this experiment, the calorific value of gas product is (81-343) kcal/NM^3 for the gases from the first experiment and (263-516)kcal/NM^3 for the gases from the second experiment. This value is regarded as reasonable figure because the injected gas used in this experiment is air. The product gas is dependent on whether air, oxygen, or a steam/oxygen mixture is injected and there are numerous other factors can affect the product gas such as coal type, seam thickness, gas input volume, type of gas input etc. (Probstein & Hicks, 1982) and also the availability of gasification channel as shown by this experiment.

CONCLUSIONS

The result of the experiment show that in an underground coal gasification conducted in laboratory using a simulation reactor, a gasification channel is a rate limiting factor. This gasification channel affects the production of gases and also its quality. The result shows that the first reactor without a channel inside produces less amount of gases (CO_2; C_nH_m; CO; H_2; C_3H_8 and CH_4) compared the gases from the second reactor which has a channel inside. The gasification process in the first experiment is not as effective as the gasification process in the second experiment. It is indicated by the calorific value of product gas from the first experiment which is in the range of (81-343)kcal/NM^3, while the calorific value of gas from the second experiment is in the range of (263-516)kcal/NM^3.

This is also supported by the temperature of the experiment. T_1 in the first experiment is in the range of (335-565)^{o}C; and T_2 is in the range of (110-240)^{o}C. On the other hand, T_1 of the second experiment is in the range of (550-705)^{o}C; while T_2 is in the range of (160-628)^{o}C. Besides that, the pattern of temperature changing from the experiment is different. For the first experiment, the pattern of T_1 has a decreasing tendency during the gasification progressing. The same pattern also occures for T_2. On the other hand, the pattern of T_1 and T_2 in the second experiment has an increasing tendency in relation with the progress of the gasification.

It can be concluded that the success of the underground coal gasification depends on the gasification channel foming during the run of the gasification. The channel gasification is one of the main parameter and becomes rate limiting factor in this underground coal gasification although there are numerous other factors can affect the gasification process such as coal type, seam thickness, gas input volume, type of gas input etc. Further experiment is suggested to examine the effect of these other factors to the gasification.

REFERENCES

Armitage,M., and Green, M.B., 2001, *Underground Coal Gasification in the United Kingdom*, 18th International Pittsburgh Coal Conference, December 2001, Newcastle, Australia.

Dinsmoor, B., et al., 1978, *The Modelling Cavity Formation During Underground Coal Gaification*, Journal Of Petroleum Technology, Vol.,XXX, May 1978, p. 695-703.

Edgar, T.F., 1974, *The Potential of Insitu Coal Gaification in The South West United State*. Paper Presented at Project Independence Hearings, Houston, Texas, Sept.18, 1974.

Gunn, R.D., et al, *1978, A Permeation Theory For Insitu Coal Gasification,* Society of Petroleum Engineers Journal, October 1978, hal. 300-314.

Probstein, R.F., Hicks R.E., 1982, *Synthetic Fuels, International Student Edition*, McGraw-Hill Inc, p.207.

Schrider, L.A., Whieldon, C.E., 1977, *Underground Coal Gasification, A Status Report,* Journal Of Petroleum Technology, vol.,29, Sept. 1977, p. 1179-1185.

Skafa, P.V., 1960. *Underground Gasification of Coal*, UCRL-Trans-10880, Moscow.

Thorness, G.B., et al., 1978, *Insitu Caol Gasification, Model Calculationa and Laboratory Experiments, Society of Petroleum Engineers Journal*, April 1978, hal. 105-116.

Wieber D.H., Sikri, A.P., 1978, *The Development Of Insitu Process For Energy And Fuels From Coal*, Mining Engineering, vol.,30, no. 5, p. 557-563.

Naskah masuk: 24 Juni 2008
Naskah diterima: 10 Juli 2008