Syngas Underground Coal Gasification (UCG) Testing of Fracture Type Subbituminous Coal in Laboratory Scale

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ABSTRACT

Underground Coal Gasification is a method used to convert underground coal seams into a gaseous product commonly called synthetic gas through a flammable chemical process without going through a conventional mining process. The UCG concept was first developed in England which was then continued by the Soviet Union in field trials of UCG which was used as a power plant. In Indonesia, Tekmira has begun to research UCG, but there are very few publications on UCG. Therefore, it is necessary to conduct research on laboratory scale UCG for analysis of gas products to support the study of renewable energy. UCG testing begins with sample preparation followed by laboratory-scale coal gasification testing. There is a sample of coal used in the test, namely Subbituminous Coal from Tanjung Enim, South Sumatra. Initial combustion is carried out by flowing propane gas into the reactor tube using a burner. Furthermore, a mixture of oxygen gas and compressed air is used to keep the coals burning. After obtaining the gas from the combustion, then gas sampling is carried out using a suction pump which will be stored in a tedlar gas bag. Combustion gas products will be checked for syngas concentration using a Gas Chromatography tool to determine the concentration of CH₄, CO₂ and O₂ gases. From the tests that have been carried out, the gas concentrations of O₂ are 3.67%, CO₂ 41.51%, and CH₄ 6.93%. Coal in the confined test conditions has good conditions with indications of seeing the concentration of CH₄, O₂, and CO₂ gas.

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1. INTRODUCTION

Underground Coal Gasification (UCG) is an in situ gasification technology of coal into combustible gas to produce synthetic gas (syngas) that can be used as power plants, chemical raw materials and other fuels. UCG is a process used to produce gases, especially hydrogen, carbon monoxide, carbon dioxide, and methane by partially burning underground coal in the presence of water and a controlled oxygen supply [1][15][16].

The UCG concept was originally developed in England by William Siemens. The concept was later developed in the Soviet Union and UCG technology was discovered in 1930 and lasted more than 50 years. Field trials and several commercial projects have been built for power plants, such as in Angren, Uzbekistan which is still operating well. In America more than 30 pilots were tested for bituminous, sub-bituminous and lignite coal types between 1975-1996. Since 1991 China has conducted sixteen tests and some of them have been commercialized. In Europe, one in the North Sea, has operated fifteen pilot scales in several different locations. In 2000, Australia started a sizable pilot project in Chin-chilla to produce syngas and is already producing five barrels/day [2][17][18].

There are still few publications on laboratory-scale UCG testing in Indonesia, therefore researchers need to conduct a laboratory-scale Underground Coal Gasification test in order to obtain UCG gas products. The test was carried out using sub-bituminous coal from the Air Laya Tanjung Enim mine, South Sumatra.

Tests carried out by researchers will produce a gas product commonly called syngas. The gas product is accommodated in a tedlar gas bag which is then analyzed for the gas concentration. Gas concentrations that can be tested using a GC device in the laboratory are CO, CH₄, CO₂. Based on UCG research conducted in Japan, the gas products produced consist of CO, CH₄, CO₂, and H₂ gas [3][19][20]. Coal combustion gas products (syngas) from UCG testing can be used for power plants, industrial raw materials, motor vehicle fuels and diesel fuel where previously the gas has been cleaned [4][21]-[24]. Therefore, the researchers analyzed the effect of coal rank and combustion temperature on the gas concentration resulting from the laboratory-scale for Underground Coal Gasification test.

2. RESEARCH METHOD

2.1. Research Location

This study took place in Tanjung Enim, a city famous for its coal products located in South Sumatra. Coal extraction site at Airlaya mine Tanjung Enim, South Sumatera at coordinate point x:363615, y:9583808. The average temperature in Town Site Base Camp (TSBC) Tanjung Enim is between 22° – 33° C, with average sunlight radiation of 45%, high humidity, and wind speed between 2.3 km/h – 4.5 km/h [5].

Figure 1. Coal Sampling Location (Source: Goggle Maps)

2.2. Coal Sampling Technique

Classification of Coal used as a sample of coal to be studied, using subbituminous coal with calories 5100 with mine brand PTBA AL 51 (5001 - 5200 kcal/kg, ar). This coal sample was taken at coordinate point x:363615, y:9583808 or at a coordinate point of 3°43'16.315"LS, 103°42'30.463"BT on Figure 1.

2.2.1. Sampling Location

The site location of the coal sampling can be seen in Figure 2. For Coal Sampling taken. The representative part of the material body (coal) for the test/analysis is used to determine the characteristics of the original material. Taken by the correct/appropriate method and protected against contamination/alteration. The coal extraction was conducted directly by researchers and accompanied by a PT Laya Water Coal Mining task force team. Bukit Asam is directly on coal mining.

Figure 2. Coal Sampling Site Location

2.2.2. Fracture-Type Coal

Fracture is where the condition of coal in the underground layer has undergone breaking or melting process to create cavities in the coal seam. In this UCG prototype model, it is assumed to be the same as that.

Figure 3. Fracture-Type AL 51 Coal

2.3. UCG Prototype

As shown in figure 4, the injection in the UCG prototype is water, nitrogen, and oxygen, for the air tubes provided (No. 1 and No. 2). Each air tube used as an injection will be controlled by a regulator (No. 4). The prototype output is two lanes where the first line for the burn test and the second for the syngas reservoir are produced. The initial combustion or starting point here uses a glow plug with a specification of 24 volts and 20 Ampere (No. 16).

Figure 4. Underground Coal Gasification Prototype Design

The details of the components contained in the UCG prototype tool show on table 1 on this below:

Table 1. Description of the Underground Coal Gasification Prototype Design Drawing

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No	Description	No	Description
1	Oxygen Tank	10	Filter
2	Nitrogen Tank	11	Combustion
3	Air and Steam Tank	12	Tube
4	Regulator	13	Hose
5	Gun Mixer	14	Conector Hose
6	Check Valve	15	Conector Tube
7	Pressure Gauge	16	Glow Plug
8	Gate Valve	17	Plug
9	Cooler		

2.4. Stages of Testing with UCG Prototype

The testing phases of subbituminous coal samples used in this study include:

- Stage of analysis of ultimate and proximate coal samples.
- This stage is a sampling process conducted in the laboratory of the coal transport handling task force (PAB) PTBA.
- Coal burning testing phase (UCG) using UCG prototype conducted at AKIPBA Tanjung Enim.
- Syngas testing stage.

Figure 5. Flow chart of the experiment

2.4.1. Injection Process

The injection process is done through an injection pipe, which measures 1/2 inch as much as three injection pipes for each injection in the form of gas, Air, Oxygen, and Nitrogen. All three injections will be inserted into the coal seam simultaneously or in the presence of mixing. Then it will go into 2 UCG combustion holes. The percentage amount of each injection is what will be the material when data retrieval. The percentage setting of each injection will use an analog regulator, and each channeling pipe will be given a valve.

In the process, there is an output hole for syngas exit in the form of brass pipes with a diameter of 1/2 inch. The impact of the different percentages of each injection will undoubtedly have different temperature values, which are measured using thermocouples at some point of combustion temperature to describe the spread of gasification. During syngas production, the syngas output pipe will be connected to the container tube. The temperature obtained in the UCG process describes the spread of gasification with the maximum temperature estimated to be measurable in the coal seam at about 1000 °C.

2.5. Coal Sampling Test

2.5.1. Proximate Analysis

Proximate analysis showed the percent of the weight of fixed carbon, volatile materials, ash, and moisture content in coal. The amount of fixed carbon and volatile materials directly contributes to the heat value of coal. Fixed carbon acts as the primary heat generator during combustion, while the high content of volatile materials indicates the ease of ignition of fuel. Ash content is important in the design of furnace grate, combustion volume, pollution control equipment, and system handling of ash in furnaces. The proximate analysis for different types of coal is given in the table 3 below:

Table 2 . Coal Proximate Analysis

Parameters	India	Indonesia	South Afrika
Moisture	5,98	9,43	8,5
Ash	38,63	13,99	17
Volatile matter	20,70	29,79	23,28
Fixed Carbon	34,69	46,79	51,22

Source: Efisiensi Energy for Asia Industry, 2017.

Generally, from the table 2 on above we know to determine the quality of coal is carried out chemical analysis on coal, which includes proximate analysis and ultimate analysis. Proximate analysis is done to determine the amount of water (moisture), flying substances (volatile matter), solid carbon (fixed carbon), and ash content (ash). In contrast, ultimate analysis is done to determine chemical elements in coal such as carbon, hydrogen, oxygen, nitrogen, sulfur, additional elements, and rare elements. Size (coal size)The size of coal grains is limited to a range of fine grains (pulverized coal or dust coal)and coarse grains (lump coal). The finest grains are for a maximum size of 3 millimeters, while the roughest grains are up to 50 millimeters in size.

2.5.2. Ultimate Analysis

The ultimate analysis is a laboratory analysis to determine the ash, carbon, hydrogen, oxygen, and sulfur content in coal with specific methods. The content is expressed in percent on the base and the sample is dried at 105 °C in moisture-free, and ash-free ultimate analysis is performed to determine carbon levels (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). The ultimate analysis for different types of coal is given in the table 3 below:

Table 3. Coal Proximate Analysis

Parameter	India (%)	Indonesia (%)
Moisture	5,98	9,43
Mineral (1,1 x ash)	38,63	13,99
Carbon	41,11	58,96
Hydrogen	2,76	4,16
Nitrogen	1,22	1,02

Source: Efisiensi Energy for Asia Industry, 2017.

2.6. Underground Coal Gasification Prototype Testing

Underground Coal Gasification testing conducted has the same principles as those in the field. The testing process is conducted in a confined state to represent the state contained in the earth's surface. As seen in the injection image on the UCG prototype of water, nitrogen, and oxygen, the air tubes that have been provided can be seen in Figure 6 a). Each air tube used as an injection will be controlled with a regulator, as can be seen in Figure 6 b). And the prototype output is two lanes where the first line for the burn test and the Syngas Underground Coal Gasification (UCG) Testing of Fracture Type Subbituminous Coal in Laboratory Scale

second for the syngas reservoir produced. Initial combustion or starting point here using glow plug with specification 24 volt and 20 Ampere Figure 6 c).

Figure 6. a) Air Tank, b) Oxygen Regulator, dan c) Combustion Chamber.

The gas that has been produced with a possible temperature of 1000 °C so that it must be cooled with a cooler can be seen in the picture then passes through the filter as the last filter before being accommodated in the reservoir. This filter functions to filter out water vapor that is not needed in the reservoir. The initial step of the glow plug is heated for the initial ignition of the coal. After combustion occurs, the required injection is injected into the combustion. Shortly after the coal burns the glow plug is turned off. Combustion occurs in the combustion chamber and the temperature can be determined through a thermocouple. If combustion has occurred, syngas is expected to be produced. This can be known through a pressure gauge with a maximum specification of 49 psi. When the fire test is carried out, the gate valve is opened as needed if the end of the pipe exits gas and burns. In this case, syngas has been produced which will later be captured and accommodated in a container for testing in the laboratory. In laboratory tests, it will be known what content is in the syngas.

3. RESULTS AND DISCUSSION

3.1. AL 51 Sample Coal Characteristics

Coal quality is the chemical & physical properties of coal that can affect its potential use. Determined by maceral and mineral content and rank and determined by chemical & physical analysis of coal. Each type of coal has a different composition. Proximate coal content testing is needed to determine the character and composition of coal, physically, chemically, and fuel properties of the coal that will be used in the gasification process. Proximate analysis of the subbituminous AL 51 coal type shows the moisture, volatile matter, ash and fixed carbon content in the coal. This sampling was carried out in the Coal Transport Handling Unit (PAB) laboratory of PT. Bukit Asam as shown in Table 2.

Table 4. AL 51 Coal Proximate Analysis

Coal Analysis Proximate Subbituminous AL 51	
Seam	A1
Calorific Value (kkal/kg, ar)	5100
Moisture (% , abd)	12.84
Ash Content (% , abd)	5.42
Volatile Matter (% , abd)	40.21
Fixed Carbon (% , abd)	41.52

Source: PAB Laboratory PT. Bukit Asam 2021.

The ultimate test of coal content is needed to determine the character and composition of the coal, physically, chemically, and fuel properties of the coal that will be used in the gasification process. Proximate analysis of the subbituminous AL 51 coal type shows the content of carbon, hydrogen, sulfur, nitrogen, and oxygen on coal. This sampling was carried out in the Coal Transport Handling Unit (PAB) laboratory of PT. Bukit Asam as shown in Table 3.

Table 5. Analysis Ultimate Subbituminous AL 51

Coal Ultimate Analysis Subbituminous AL 51	
Seam	A1
Calorific Value (kkal/kg, ar)	5100
Carbon (%adb)	59.62
Hydrogen (%adb)	4.72
Nitrogen (%adb)	0.84
Sulfur (%adb)	0.56
Oxygen (%adb)	28.64

Source: PAB Laboratory Bukit Asam 2021.

Based on the coal proximate analysis results in Table 3, the type of coal can be determined using the Coal Base Conversion Table (ASTM D385, 2005, American Society for Testing and Materials). This classification is based on the rank of the coal or based on the degree of its metamorphism or changes during the coalification process (ranging from lignite to anthracite). The data on fixed carbon (dmmf), volatile matter (dmmf), and calorific value in Btu/lb are needed on the basis of mmmf (moist, mmmf) to determine the rank of coal.

3.2. Underground Coal Gasification Product Test Results

3.2.1. Effect of Temperature and Pressure on Underground Coal Gasification Testing Process on Syngas Produced

The test was carried out using a sample of AL 51 sub-bituminous coal of fracture type taken from the Air Laya TSBC (Town Site Base Camp) location, Tanjung Enim, with an oxygen injection of 3L/ minute as the gasification agent. Based on the experiments that have been carried out, the following results as below:

Table 6. Analysis Ultimate Subbituminous AL 51

Gasification Agent	Flow Rate	Data Collection Time 5 Minutes		Temp. Combustion (°C)	Exit Pressure (Psi)	Test On (Fire)	Weight Before/After Data Retrieval
Oksigen (O ₂)	3 L/ minute	Ignition time	0	0	0	-	Before burning process 2 kg/ After burning process 0.55 kg
			0	80	0	-	
			0	110	0	-	
		0	0	696	0,8	-	
		1	5	787.7	1.14	light up	
		2	10	536	0.36	Not	
		3	15	288.6	0.878	Not	
		4	20	630,7	1.897	light up	
		5*	25	547.5	1.44	light up	
		6	30	315.1	2.1	light up	
		7	35	541.8	1.43	light up	
		8	40	559	1.741	light up	
		9	45	586.6	1.483	light up	
		10	50	634.1	0.745	Not	
		11	55	594.8	0.9	Not	
		12	60	490.1	1.15	light up	
		13	65	506.2	1.18	light up	

The part of the column marked in red (5) is the time for sampling the test data. In testing the fracture type AL 51 subbituminous coal sample weighing 2 kg, in the gasification process oxygen injection is given with a flow rate of 3L/minute. In the fifth test data in the twenty-fifth minute, the pressure was recorded at 1.44 Psia and the combustion chamber temperature was 547.5 °C where the coal sample was tested, the

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combustion test was lit perfectly. The weight of the 2 kg coal sample after the 65 minute testing process on the UCG prototype was recorded at 0.55 kg. The flame is an indication of the output gas produced by the UCG prototype. And some of testing do not light up when high temperatures are possible because there is a residual blockage.

Figure 7. Effect of temperature on gasification process of Subbituminous AL 51

The gas produced, syngas, is accommodated in a gas bag, for later analysis of its gas composition. Then the data on the test results of the fracture type AL51 subbituminous coal sample is displayed. Based on the gasification process data using the UCG prototype that has been obtained, a graph of the temperature of the AL 51 subbituminous coal sample of fracture type can be made as table 6 above and the graphic of temperature during process of gasification show on Figure 7.

Figure 8. Effect of Pressure on the gasification process of Subbituminous AL 51

In the measurement of the combustion chamber test temperature for gasification, for samples of fracture type coal type, a flame starts to appear at the end of the burn test pipe until it no longer lights up, for 65 minutes for fracture type coal. Furthermore, the pressure changes recorded during the test from fractured and in-situ coal samples can be seen in Figure 8. In the gasification process using the UCG prototype on fractured coal samples, there is a pressure difference during the gasification process between fracture type and in-situ type gasification. Figure 8 shows an increase in pressure when the test data for the fuel test is recorded to be lit at the end of the pipe when the gate valve is opened. The highest pressure in the fracture sample was measured at 2,1 Psi at the 30th minute and the lowest pressure at 0,74 Psi at minute 50.

Table 7. Average and difference between UCG Gasification Process Temperature and Pressure

Coal Sample Type	Temperature (°C)	Pressure (Psi)
AL 51 Fracture	551.014	1.23

Table 7 shows the average temperature and average pressure in the gasification process for coal subbituminous AL 51 samples at 551,014 °C and 1.23 Psi.

3.2.2. Syngas Composition Analysis

Researchers conducted tests on gas products or called syngas, which was produced to determine in-situ type coal and coal type fractures against syngas production if using the Underground Coal Gasification (UCG) method, which is accommodated in Tedlar gas sampling bags. The concentration analysis of the gas

content of the product, syngas, is distinguished by the influence of coal ratings and combustion temperatures in the laboratory. UCG research with laboratory-scale prototypes is expected to be a crucial first step towards coal utilization, especially low-ranking coal.

The test was carried out using samples: the fracture type subbituminous AL 51 coal sample. Based on the analysis that has been carried out, the syngas composition obtained is in Table 8.

Table 8. UCG Syngas Composition

No.	Sample AL 51	Sampling Temperature	Parameters of Result Analysis				
			O ₂ %	CO ₂ %	CH ₄ %	H ₂ S (ppm)	Others %
1.	Fracture	608 °C	3.67	41.51	6.93	5163	47.38

Source: Polytechnic of Sriwijaya Laboratory May 29th 2021.

Tests carried out on fracture-type subbituminous coal found; CH₄ gas concentration of 6.93 %, O₂ 3.67 %, CO₂ 41.51%, H₂S 5163 ppm (0.51%) and others 47.38%. Where the Coal Sample Test subbituminous AL51 Fracture Type is by sampling The test is carried out at a temperature of 547.5 °C. Tests carried out on fracture type sub-bituminous coal found a relatively low CH₄ gas concentration of 6.93%. Based on the theoretical literature on coal rank differences, sub-bituminous coal produces CH₄ gas between 1% - 5% [10].

This test resulted in fracture type subbituminous coal which is relatively larger than this value because the distribution of the gasification agent, namely O₂ gas, is evenly distributed throughout the temperature sample when gas sampling is 547.5 °C. In addition, the fracture type coal samples were physically in the form of fragments and the methane content in the coal samples began to disappear. This is due to complete combustion. In the fracture sample, from 2 kg there is still 0.55 kg remaining. This condition is possible because the coal has not burned completely due to the short testing time.

4. CONCLUSION

From the research conducted, it can be concluded that: There are 3 gas products from the Underground Coal Gasification test, namely CH₄ gas, CO₂ gas and O₂ gas, which are syngas from coal gasification testing. The largest gas concentration is the concentration of CO₂ gas in the fracture type sample of 41.51%. These results indicate that the tests carried out on the fracture type subbituminous Coal Sample Test, as an example of gasification conditioned by the coal lump sample which is still the same as the original, namely below the ground surface has combustion conditions with an indication of the concentration of O₂ gas which is the gasification agent injected measured at 3.67% and higher CO₂ gas. Low rank coal (Sub-bituminous Coal) produces less concentration of syngas products (CH₄) from Underground Coal Gasification (UCG) test results 6.93% and others 47.38 % can not detect because of gas analyzer limitation.

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