Characteristics Analysis of Char Resulted from Low Rank Coal Gasification

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Abstracts- **The coal gasification process in this study aims to increase the quality of low rank coal from lignite type to coal with semi-anthracite and anthracite grades with higher fixed carbon values. The gasification process is carried out at temperatures between 700 and 900°C. In the initial stages the aim of the work is to study the relationship between gasification temperature and the mass of coal and the time for gasification process. Proximate and ultimate analyses were carried out to determine the characteristics of the raw materials used and the coal char produced from combustion. The results of the analysis are used to calculate the fuel ratio as the parameter to determine the grade of coal. In addition, a SEM-spot EDS analysis was carried out on the gasified coal solids to ensure the fixed carbon content produced from the above process. The results showed that gasification process can raise the grade of low rank coal into char products with semi-anthracite to anthracite grades with fuel ratio reached 10.84. Results from product analysis of the LRC coal gasification using SEM-Sport EDS showed that the atomic percent of element C was very high, reaching 98.58%, corresponding to mass percent of 90.74%, with remaining inorganic elements less than 1.5% (as Al, K, Si and S).**

Keywords- **low rank coal, char, fuel ratio, gasification**

I. Introduction

Charcoal is a carbon-rich solid residue as remaining when coal is burned at high temperature without or with limited air until some of its volatile substances are lost. Characteristics of combustion results are influenced by physical-chemical properties, interactions between particles of coal, combustion temperatures and types of raw materials for coal to be burned [1]. Charcoal at high temperatures will become soft, devolatilized, and expands. When solidify again, it forms porous material. Now more research on the use of char as raw material to produce energy or chemical compounds through gasification or pyrolysis process is done by a number of researchers, including [2], [3], [4],[5] and gasification has the advantage of higher efficiency and greater flexibility compared with pyrolysis process [4].

The role of Char in energy development is very important. Char gasification process can raise the temperature of gasification up to 1200°C in a very short time only 25 minutes [6]. Charcoal can be used to form coke via pyrolysis process.

Coke produced from bituminous coal is generally denser and relatively strongerthan charcoal. Due to increasing demand of iron and steel, there has been a considerable increase in the coke oven capacity which resulted increase output of coal chemicals [7]. The development of upgrading low rank coal is an effort to increase the calories of low rank coal. Researchers have tried various technologies in the process of upgrading LRC including the HWD (hot water drying) method, which is cooking coal with water using an autoclave with high pressure and temperature (100 bar pressure and 300-450°C). It is expected that with this process water bound in the coal will come out and the chemical structure of the coal will change, the formed tar will close the pores in the coal which causes that at high pressure conditions the coal will not absorb water, so there will be a reduction in water content (inherent moisture) in coal [8].

Another upgrading process often carried out is the pyrolysis process, namely the process of burning or drying coal without air at high temperatures (300-550°C). During the pyrolysis process, volatile matter which is bound in the internal pores of the coal will come out. Low rank coal contains high water content between 65 and 80 percent. Its calorific value is less than 5,000 kcal, so it is less efficient when used as direct fuel. Low rank coal usually is soft, easily broken, easy to powder and easily burnt. Geo Coal technology can increase coal calories by 50-100 percent. In addition, the upgrading process can also maintain sulfur and ash levels remain low so that the coal produced is more environmentally friendly. The development process by Wei Tong [9] about volatile and char combustion. Char reduced the initial temperature and final temperature of fuels. The interactions firstly inhibited and then facilitated.

Coal contains *mineral matter* which will turn to ash after burning. Ash is composed of mineral components, mainly alkali metals such as K and Na and alkaline earth metals such as Ca or Mg. *Mineral Matter* is a material *non-carbonaceous* in coal which can reduce the calorific value of the coal, which mostly consists of silicate salts, aluminate, sulfates, carbonates and sulfides from sodium, potassium, calcium, magnesium, titanium and iron [10] and the existence of ash element will cause environmental problems.

Besides mineral matter coal also contains *Volatile Matter* (VM). The VM of the coal is determined by the weight loss that occurs when the coal is heated without contact with air at a temperature of approximately 950°C with a certain heating rate. This weight loss is the loss of gas content of H_2, CO, CO_2, CH_4, and steam and a small portion of tar. The content of flying substances affects the perfection of combustion and the intensity of the flame. The high content of flying substances will further accelerate the combustion of carbon materials and vice versa. The ratio between the carbon content is tethered to the content of flying matter expressed as the *fuel ratio* (see tabel 1 below) which is used to indicate the *rank* of coal. The higher the *fuel ratio*, the more the unburnt carbon [16].

TABEL I. COAL CLASS FUEL RATIO

	Coal Class	Fuel ratio
1	Coke	92
2	Antrasit	24
3	Semi Antrasit	8,6
4	Semi Bituminous	4.3
5	Bituminous Low Volatile	2.8
6	Bituminous Medium Volatile	1.9
7	Bituminous HighVolatile	1.3
8	Lignit	0.9

The calorific value of coal, is the sum of the heat of combustion from combustible elements in the coal (such as carbon, hydrogen and sulfur), is reduced by the heat of decomposition of *carbonaceous* and added or reduced by the exothermic or endothermic reaction of combustion of impurities in the coal. Calorific value, expressed as *heating value* and *Gross Heating Value* (GHV), is obtained by completely burning a coal sample in a *bomb calorimeter to* produce CO_2 gas, SO_2, water and nitrogen. Coal generally used as fuel is called fuel coal (*steaming coal, fuel coal*,or *energy coal*), whilst bituminous coal for making coke is called coke coal (*cooking coal)* and coal that is used as other energy base material is called conversion coal.

Low rank coal used in this study has high content of moisture, volatile matter and inorganic compounds. In order to reduce these three parameters, the low rank coal upgrade was carried out by adding used cooking oil during the gasification process. The goal is to coat the pores of coal particles that water can not re-enter the coal [11]. The results of charcoal are analyzed by proximate and ultimate analyses, whilst the characteristics of charcoal products are analyzed by the Gray King Coke Type method [17].

II. RESEARCH METHODS

The research was conducted at a laboratory scale with low rank coal raw materials obtained from PTBA Tanjung Enim. The upgrading tool used is the Up-draft Gasifier which is made of steel insulated with bricks and cement, equipped with ceramic plates where the coal is burned and a blower for air requirements in the gasification process. A thermocouple is installed above the gasifier to measure the temperature of the process (figure 1)

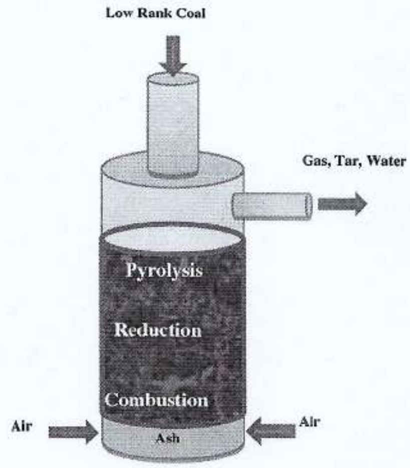

Figure 1. Low Rank Coal Up-draft Gasifier type

The research begins by pretreatment of raw materials in the form of size reduction so that the combustion process of low rank coal is more homogeneous. The flow diagram of the research procedure can be seen in the figure 2.

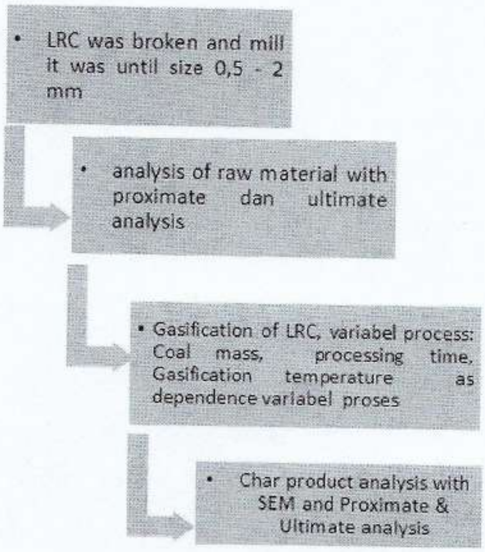

Figure 2. Flow diagram of research procedure

III. RESULTS AND DISCUSSION

The results of the study are divided according to the stages of the study as follows:

A. Effect of coal mass on coal gasification temperature of char making process

Coal upgrading aims are to eliminate water content and to reduce the content of inorganic compounds so that fixed carbon values rise and automatically increase the calorific value of the coal. Experiment on the effect of coal mass on the temperature of the gasification process for each type of coal was done by varying the amount of coal burned at 5 kg and 7 kg. This research also use waste cooking oil as solvent at 7 kg, in order to see how it affects the process temperature and the quality of char produced. The results can be seen in the graph below:

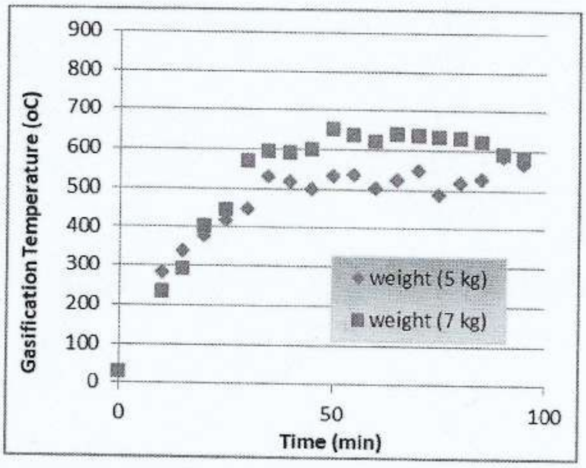

Figure 3.a. Effect of coal mass on gasification temperature for heat 4600 kkcal/kg

On the graphs from Figures 3a and 3b., it is clearly visible the effect of mass and heat of coal on temperature increases in the gasification process. At 4,600 kkcal/kg the maximum gasification temperature only reaches 653°C in the 50th minute and then starts to fall slowly, while for coal of 5,000 kcal/kg the gasification temperature reached up to 750°C from the 40th minute and continues constant until the 85th minute. This shows that the lower the heat of coal, the faster the inorganic material turns to ash which decreases the gasification temperature. Lignit semi char pyrolysis upgrading temperature has on particulate matter emission, char product at 350°C has the best combustion reactivity and char produced < 350°C has lowest particulate matter emissions [12].

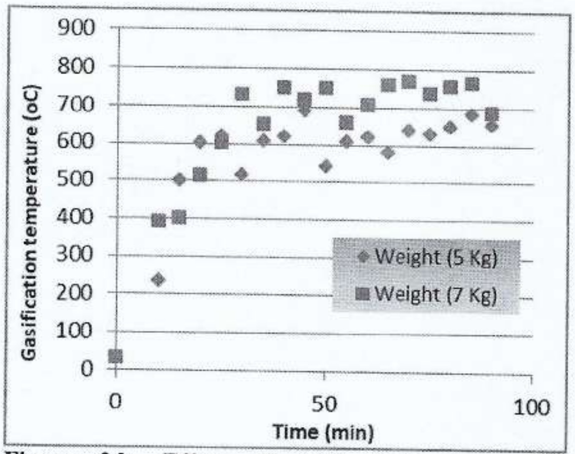

Figure 3.b. Effect of coal mass on gasification temperature for heat 5000 kkcal/kg

On coal of 5,000 kcal/kg, the inorganic material is smaller and the fixed carbon is greater and temperature drop only occurs in the 90th minute. Hence, semi coke and bituminous coal blend indicated that the ignitionand burnout temperatures of blends decreased as the blending ratio of bituminous coal increased and there existedsignificant interaction between semi coke or anthracite and bituminous coal and semi coke had better combustion behavior and lower NO conversion ratio compared to anthracite, which mainly resulted from more porousstructure in semi coke [13].

B. The effect of used cooking oil on coal gasification temperature at 4,600-5,000 kcal/kg

The use of waste cooking oil is intended to increase the combustion heat produced and to accelerate the formation of char/coke. The method used is to immerse coal with certain amount of oil before burning it. The combustion is carried out and the effect of the addition of used cooking oil to the temperature of the gasification is analised. The results are shown in the graph below:

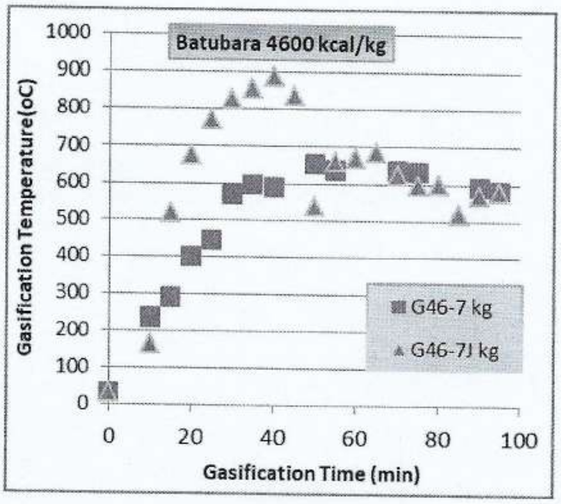

Figure 4a. The effect of used cooking oil on coal gasification temperature 4600 kcal/kg

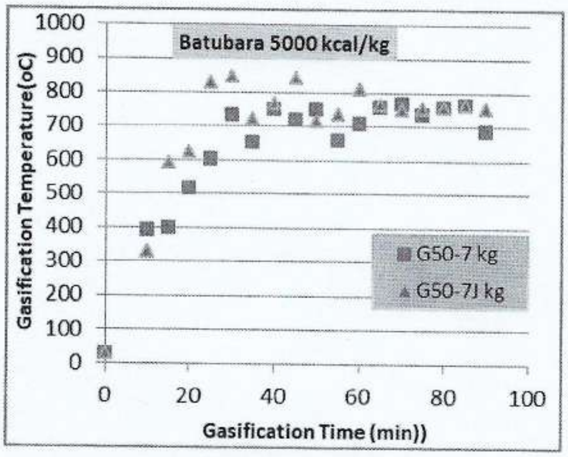

Figure 4b. The effect of used cooking oil on coal gasification temperature 4600 kcal/kg

Immersion of *low rank coal coal* with used cooking oil affects the temperature of gasification. Temperature increase is visible up to 889°C. This is because the vegetable hydrocarbon content in used cooking oil has increased the temperature of combustion gasification. As for coal 4,600 kcal/kg, the temperature decreases very dramatically. Between 45th minute and 90th minute the gasification temperature dropped to 580 °C. Whilst for coal of 5,000 kcal/kg the decrease occurred more slowly and the lowest temperature was 754°C, in the 90th minute.

C. *Characteristics of char gasification of low rank coal with proximate and ultimate analysis*

1) *Proximate Analysis of Char Products from Low Rank Coal*

TABLE I. PROXIMATE ANALYSIS OF CHAR PRODUCTS FROM LOW RANK COAL

Code Sampels	Moisture Content	Ash Content	Volatil Matters	Fixed Carbon
Batubara (4600 kcal/kg)	10,98	1,96	42,06	45
Weight (5 kg)	6,97	2,9	10,29	79,84
Weight (7 kg)	6,36	2,32	25,87	65,45
Weight(+ WCO)	6,36	2,22	7,72	83,7
Batubara (5000 kcal/kg)	10,92	2,72	42,14	44,22
Weight (5 kg)	6,3	6,64	6,2	80,86
Weight (7 kg)	5,18	6,08	6,66	82,08
Weight(+ WCO)	8,08	8,8	5,72	77,4

Moisture content is a parameter that can affect the quality of coal combustion. High water content will require greater *excess air*, which will result in low effectiveness and efficiency of combustion operations in the kitchen. In the process of making char, the water content will prolong the polishing process for 15-45 minutes to 1% water content. The results of the analysis show that in the low rank coal the number of moisture content is quite large but the addition of WCO solvent at 5,000 kcal/kg does not help in reducing the moisture content in coal.

The content of flying substances in coal is closely related to the *rank of* coal. The content *volatile matter* will decrease according to the increasing rank of coal. Volatile matter in LRC (4,600 kcal/kg) is very high, but the addition of used cooking oil was able to reduce volatile matter in LRC. The content of flying substances affects the perfection of combustion and the intensity of the flame. The high content of flying substances will further accelerate the combustion of carbon materials and vice versa.

Fixed Carbon is tethered carbon which is obtained by subtracting 100 from the amount of *volatile matter* and ash from dry coal. The gasification process affects the increase in fixed carbon of the product with almost the same results.

D. *The Results of the Ultimate Analysis of Char Products from All Types of Heat from Raw Coal*

Ultimate Analysis aims to determine the carbon content, hydrogen, nitrogen, sulfur and oxygen in coal. Ultimate analysis results are usually stated on the basis of *mineral matter free coal* or if coal has a small ash content expressed by *dry ash free coal*. The three elements of carbon, hydrogen and air are coal forming substances (*true coal substance*) and the comparison in coal is a determinant of the nature of coal. In the classification of coal these three elements are crucial.

TABLE II. ULTIMATE ANALYSIS OF CHAR PRODUCTS FROM LOW RANK COAL

Sampels Code	Carbon	Hidrogen	Sulfur Total	Oksigen
Batubara (4600 kcal/kg)	63,12	5,59	1,26	27,61
Weight (5 Kg)	80,54	2,48	1,66	12,04
Weight (7 Kg)	73,12	3,72	1,52	18,88
Weight (+ WCO)	83,31	2,1	1,67	10,32
Batubara (5000 kcal/kg)	64,54	5,93	0,99	25,64
Weight (5 Kg)	81,47	1,85	1,01	7,41
Weight (7 Kg)	82,38	1,81	1,16	8,37
Weight (+ WCO)	77,22	1,86	0,94	10,98

Carbon content in char from the gasification process increases with the increase in LRC coal mass. Carbon in coal is the forming of aromatic and aliphatic hydrocarbon compounds from coal and in this study the carbon element produced in coal is almost as large as the value of *fixed carbon* in coal. The hydrogen and oxygen content decreases as the mass of the gasified coal increases.

The results of the analysis of total sulfur content in char products are very small, whereas from the gasification process is greater. Sulfur compounds in coal will be very detrimental because it will cause corrosion, pollution of SO_2 and SO_3 in the atmosphere.

Efforts to produce high-quality fuels from low-rank biomass and coal are very important from the perspective of renewable energy and utilization of unused resources. The hydrothermal process of coal and biomass has been carried out by Moriyasu [14]. The results of his research show that low rank coal and biomass after hydrothermal can produce solid hydrophobic products, showing the same chemical composition, gross heating value and effective heating value. Thermogravimetric analysis shows that solid products have a wide and stable range of molecular weights for coal compared to biomass because biomass has a higher volatile content.

[1], [15] Stated that the macromolecular structure of carbon residues resulting from coal gasification has a larger pore surface area, a more ordered carbon crystal structure.

E. Char Product Quality Analysis of the results of the Gasification Process with SEM-Spot EDS

The results of the product analysis of the LRC coal gasification process using SEM-Sport EDS show the atomic percentage of element C is very high, reaching 98.58%, which correspond to mass % of 90.74%. Inorganic elements remaining in products is less than 1.5% (such as Al, Si and S).

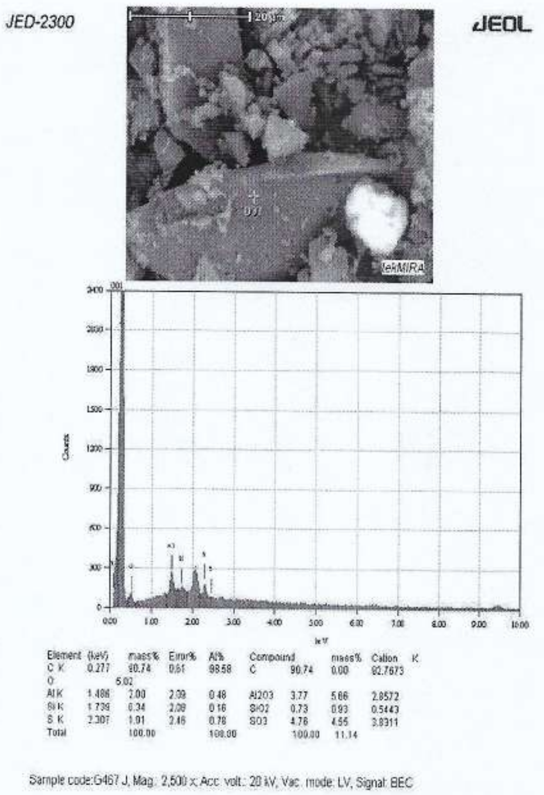

Figure 5. char product analysis using SEM-Sport EDS

F. *COAL UPGRADING QUALITY RESULTS (FUEL RATIO CALCULATION)*

The raw material for coal 4,600 and 5,000 kcal/kg is the type of Lignite-bituminuous high volatile. After upgrading with gasification process, the coal grade LRC to semi-antrachite grade with the highest gasification temperature reaching 780°C. The LRC combustion process with a gasification process produces a fuel ratio of more than 10.84, whilst used cooking oil can raise the LRC coal grade from semi-anthracite to anthracite.

Increasing the calorific value of coal which is classified from 4,600 to 5,000 kcal/gr produces a better fuel ratio with the grade achieved is semi-anthracite, yet the effect of waste cooking oil on the fuel ratio is very small, only in the range of 12.32-13.53.

TABLE III. FUEL RATIO CALCULATION AND GRAY KING ASSAY ANALYSIS

Sampel Code	Ash	Volatile Matters	Fixed Carbon	Char/Coke Type (GKA) analysis	Upgrading Result	
					Fuel Ratio	Upgrading Catagory
BB 4600 kcal/kg	1,96	42,06	45	A	1,07	Lignit-Bitumionus High Volatile
Weight (5 kg)	2,9	10,29	79,84	A	7,76	Semi bituminuos-semi antrasit
Weight (7kg + WCO)	2,22	7,72	83,7	A	10,84	Semi antrasit-antrasit
BB 5000 cal/kg	2,72	42,14	44,22	A	1,05	Lignit-Bitumionus High Volatile
Weight (5 kg)	6,64	6,2	80,86		13,04	Semi antrasit-antrasit
Weight (7kg)	6,08	6,66	82,08		12,32	Semi antrasit-antrasit
Weight (7kg + WCO)	8,8	5,72	77,4		13,53	Semi antrasit-antrasit
	ASTM D.3174	ASTM D.3175	ASTM D.3172	BS 1016		

G. CONCLUSION

The results showed that the gasification process can raise the grade of low rank coal into char products with semi anthracite to anthracite grades, where the fuel ratio reached 10.84, and from the product analysis results the LRC coal gasification results using SEM-Sport EDS showed the percentage of element C atoms was very high reaches 98.58% with mass% C is 90.74% and the remaining inorganic elements in the product are less than 1.5% Increasing the calorific value of coal which is classified from 4,600 to 5,000 kcal/gr produces a better fuel ratio with the grade achieved is semi-anthracite, yet the effect of waste cooking oil on the fuel ratio is very small, only in the range of 12.32-13.53.

ACKNOWLEDGMENT

The authors would like to acknowledge supports from Sriwijaya University for providing funding so that this research can be carried out, and many thanks to students who have helped research and write this article.

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