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# Characteristics of Char from Low-Rank Coal Gasification

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**ABSTRACT**

The coal gasification process in this study aimedto increase the quality of low-rank coal (LRC) from lignite type to coal with semi-anthracite and anthracite grades with higher fixed carbon values. The gasification process wascarried out at temperatures between 700-900 °C. In the initial stages of the study, the relationship between the increase in gasification temperature with the mass of coal and the gasification process time was investigated. The proximate and ultimate analysis wascarried out to determine the characteristics of the raw materials used and the coal char produced from combustion. The analysis results are used to calculate the fuel ratio, where the fuel ratio is a parameter to determine the grade of coal. In addition, an 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 the gasification process could raise the grade of LRC into char products with semi-anthracite to anthracite, where the fuel ratio reached 10.84. From the product analysis results, the LRC coal gasification results using SEM-EDS showed that carbon reached 98.58%. The remaining inorganic elements in the product are less than 1.5%, such as Al, Si and K.

**Keywords:** Low-grade coal, charcoal, fuel ratio, gasification.

## INTRODUCTION

Charcoal is a carbon-rich solid residue that remains when coal is burned at high temperatures without air or limited air until some of its volatile substances are lost. Characteristics of combustion results are influenced by physical-chemical properties, interactions between coal particles, combustion temperatures, and types of raw materials for coal to be burned (Shen et al., 2019; Chang'an Wang et al., 2021). Charcoal, at high temperatures, will become soft, expand, and solidify again to form porous material. Currently, charcoal is used as raw material to produce energy or chemical compounds through gasification or pyrolysis processes (Mallick et al., 2017; Tamošiunas & Jeguirim, 2019).

Charcoal can be used as coke formed in the pyrolysis process. Coke is generally denser and relatively strong, produced from bituminous coal (Sun et al., 2015; P. Wang et al., 2020). The development of upgrading low-rank coal is an effort to increase the calories of low-rank coal (Bich et al., 2017; Deska et al., 2018; Zhuo et al., 2021). Researchers have performed various processes and used different technologiesto upgrade LRC, including thehot water drying (HWD) method, which is cooking coal with water using an autoclave with high pressure and temperature (300–450 °C and 100 bar). It is expected that with this process, the 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 underhigh-pressure conditions, the coal will not absorb water, so there will be water (inherent moisture) reduction in coal (Chavda & Mahanwar, 2021). Another upgrading process often carried out is the pyrolysis process,which was burning or drying coal without air at high temperatures (300–550 °C)(Chen et al., 2021). During the pyrolysis process, the volatile matter which is bound in the internal pores of the coal will be released. Low-rank coal contained high water content between 65–80%. Its calorific value is less than 5000 kcal, so it is less efficient when used as direct fuel (Lee et al., 2021; Triyono & Suprianto, 2021). Besides, low-rank coal isusually soft, easily broken, easilypowdered and easily burnt. Geo-coal technology can increase the calorific value of coal by 50–100% (Cheng et al., 2021; Meshram et al., 2015). In addition, the upgrading process can maintain sulfur, and ash levels remain low so that the coal produced is more environmentally friendly (Belhachemi et al., 2019).

Coal contains mineral matter which will turn to ash after being burned. 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 that 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 (Holuszko et al., 2017).

Besides mineral matter, coal also contains volatile matter (VM). The VM in 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 $H_2$, CO, $CO_2$, $CH_4$, 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 used to indicate the rank of coal. The higher the fuel ratio, the more unburnt carbon (X. Wang et al., 2019).

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

With a high moisture content, volatile matter and inorganic compounds in low-rank coal, to reduce the three parameters, the low-rank coal upgrade in this study was carried out by adding used cooking oil during the gasification process. The goal is to coat the pores of coal particles so that water does not re-enter the coal. The results of charcoal wereanalyzed by proximate and ultimate, while the characteristics charcoal products wereanalyzed by the Gray King Coke Type method.

## MATERIALS AND METHOD

The low-rank coal (LRC) was obtained from local coal mining, PT. Bukit Asam, Tbk., in South Sumatra, Indonesia. The LRC was crushed and ground to obtain a size of 0.5–2 mm. The characteristics of LRC and char from gasification were examined through proximate and ultimate analysis based on ASTM standards.

The upgrading process was taken place in the updraft gasifier. The gasifieris made of steel insulated with bricks and cement, equipped withceramic plates where coal is burned and a blower for air requirements in the gasification process. A thermocouple was installed above the gasifier to measure the temperature. The surface morphology of charcoal was analyzed with Scanning Electron Microscopy Energy Dispersive X-ray (SEM-EDS JEOL JSM-6510A).

## RESULTS AND DISCUSSION

### Effect of coal mass on coal gasification temperature char making process

Theeffect of coal mass on the gasification temperature for each type of coal is shown in Figure 1. Coal upgrading aims to eliminate water content and reduce the content of inorganic compounds so that fixed carbon values rise and automatically increase the calorific value of the coal. Waste cooking oil was added to 7 kg of coal and increased the temperature and the quality of the char produced. At coal 4600 kcal/kg, the maximum gasification temperature reached 653 °C for 50 min and started to fall slowly. In contrast, for

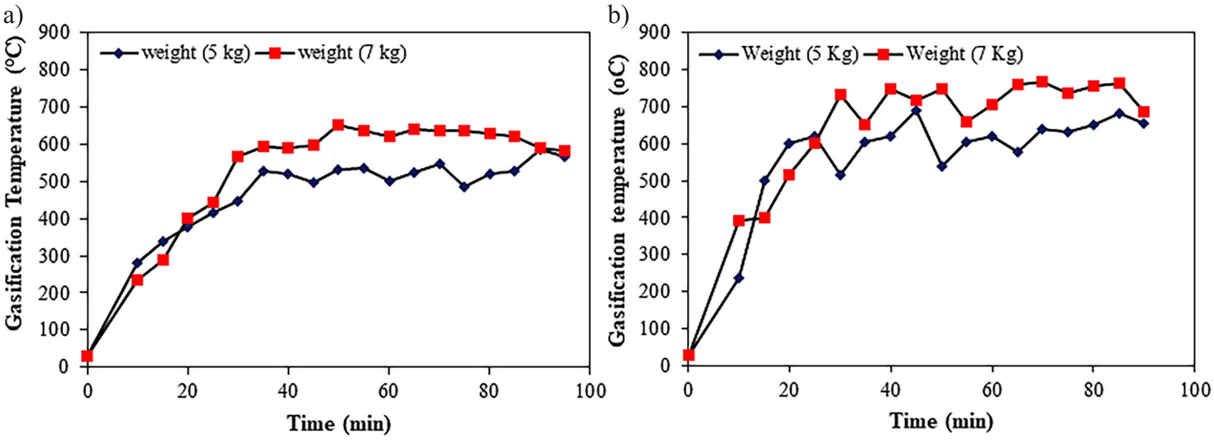


**Figure 1.** The effect of coal mass on gasification temperature for coal (a) 4600 kcal/kg and (b) 5000 kcal/kg

5000 kcal/kg coal, the gasification temperature reached 750 °C and only took 40 min. This shows that the lower the heat of coal, the faster the inorganic material turned to ash, so the gasification temperature decreased. For coal, 5000 kcal/kg, the inorganic material is smaller, but the fixed carbon is greater, making the temperature drop only after 90 min left.

## The effect of used cooking oil on coal gasification temperature 4600-5000 kcal/kg

The effect of used cooking oil on the different types of coal is displayed in Figure 2. The use of waste cooking oil wasintended to increase the combustion heat produced and accelerate the formation of char/coke. The method used wasto immerse coal which will be burned with a specified amount of oil. The combustion wascarried out and the effect of the addition of used cooking oil on the temperature of the gasification produced was analyzed as shown in Figure 2.

Immersion of *low-rank coal* with used cooking oil affects the temperature rise gasification, visible increase to 889 °C. This is because the vegetable carbon hydro content in used cooking oil can increase the temperature of combustion gasification. However, for 4600 kcal/kg, the temperature decreased dramatically in 45 min, and until 90 min, the gasification temperature dropped to 580 °C. In turn,for coal 5000 kcal/kg, the decrease occurred more slowly, and the lowest temperature in the 90 min was 754 °C.

## Characteristics of char gasification of low-rank coal by proximate and ultimate analysis

The proximate and ultimate analysis results of low-rank are shown in Table 1. Moisture content is a parameter that can affect the quality of coal combustion. The high watercontent will require greater *excess air*, resulting in low effectiveness and efficiency of combustion operations in the kitchen. In making char, the water content

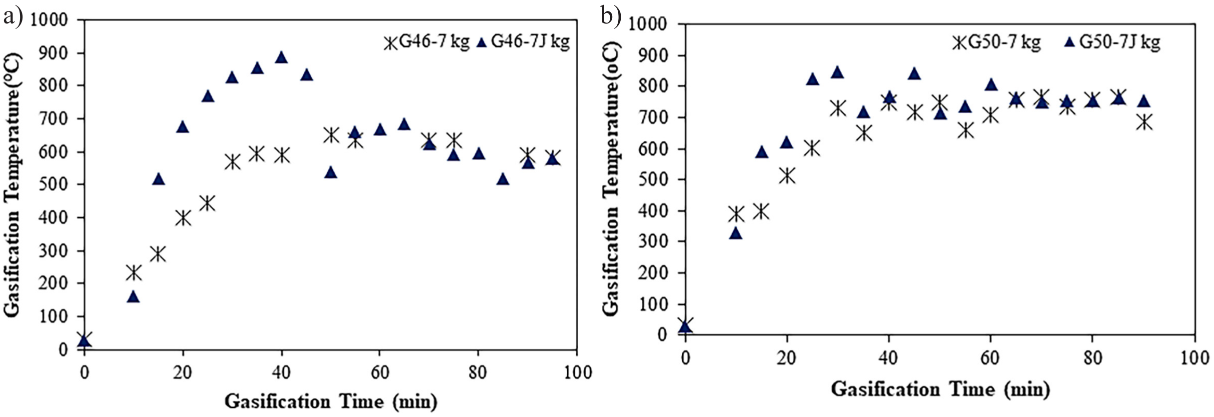


**Figure 2.** The effect of used cooking oil on gasification temperature for coal (a) 4600 kcal/kg and (b) 5000 kcal/kg

**Table 1.** Proximate analysis of char products from low-rank coal

| Code sample | Moisture content | Ash content | Volatile matters | Fixed carbon |
|---|---|---|---|---|
| Coal (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 |
| Coal (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 |

will prolong the polishing process for 15–45 min to 1% water content. The analysis showed that in the low-rank coal, the moisture content is quite large, but adding WCO solvent at 5000 kcal/kg does not significantly reduce the moisture content in coal.

The content of flying substances in coal is closely related to the *rank of* coal. The *volatile matter*content does not follow the rank of coal type, but the mesopore structure is affected by the volatile matter (Yi et al., 2021). Volatile matter in LRC (4600 kcal/kg) is quite high, but usingspentcooking oil reduced volatile matter in LRC. Thevolatilesubstances affect the perfection of combustion and the intensity of the flame. The high content of volatilesubstances will further accelerate the combustion of carbon materials and vice versa (Chao Wang et al., 2021). Fixed Carbon is tethered carbon obtained by subtracting 100 from the *volatile matter* and ash from dry coal. The highest fixed carbon content was obtained at 4600 kcal/kg coal mixed with waste cooking oil. The gasification process affects the increased fixed carbon of charcoal as the main source of heat (Feng et al., 2022). The ash content of this coal type is also low compare to others. Ash content is calculated from the ratio between the mass of ash after cooling and the initial weight of the dry sample (Kumar et al., 2021).

The ultimate analysis of charcoal consisted of carbon, hydrogen, nitrogen, sulfur and oxygen contentpresented in Table 2. Ultimate analysis was stated based on mineral matter-free coal or if coal has small ash content expressed by dry ash-free coal. On the basis ofthe analysis, the highest carbon content in coal is received when coal (4600 kcal/kg) is combined with waste cooking oil (83.31%). This is advantageous for the continued utilization of charcoal as fuel. Besides, the sulfur content of charcoal from different types and rank is relatively low (<2%).

Carbon content in gasification charcoal (5000 kcal/kg) increased with LRC mass. The carbon in coal forms aromatic and aliphatic hydrocarbon compounds from coal. In this study, the carbon element produced in coal is almost as large as the value of fixed carbon in coal (Keboletse et al., 2021). The hydrogen and oxygen content decreases as the mass of the gasified coal increase.

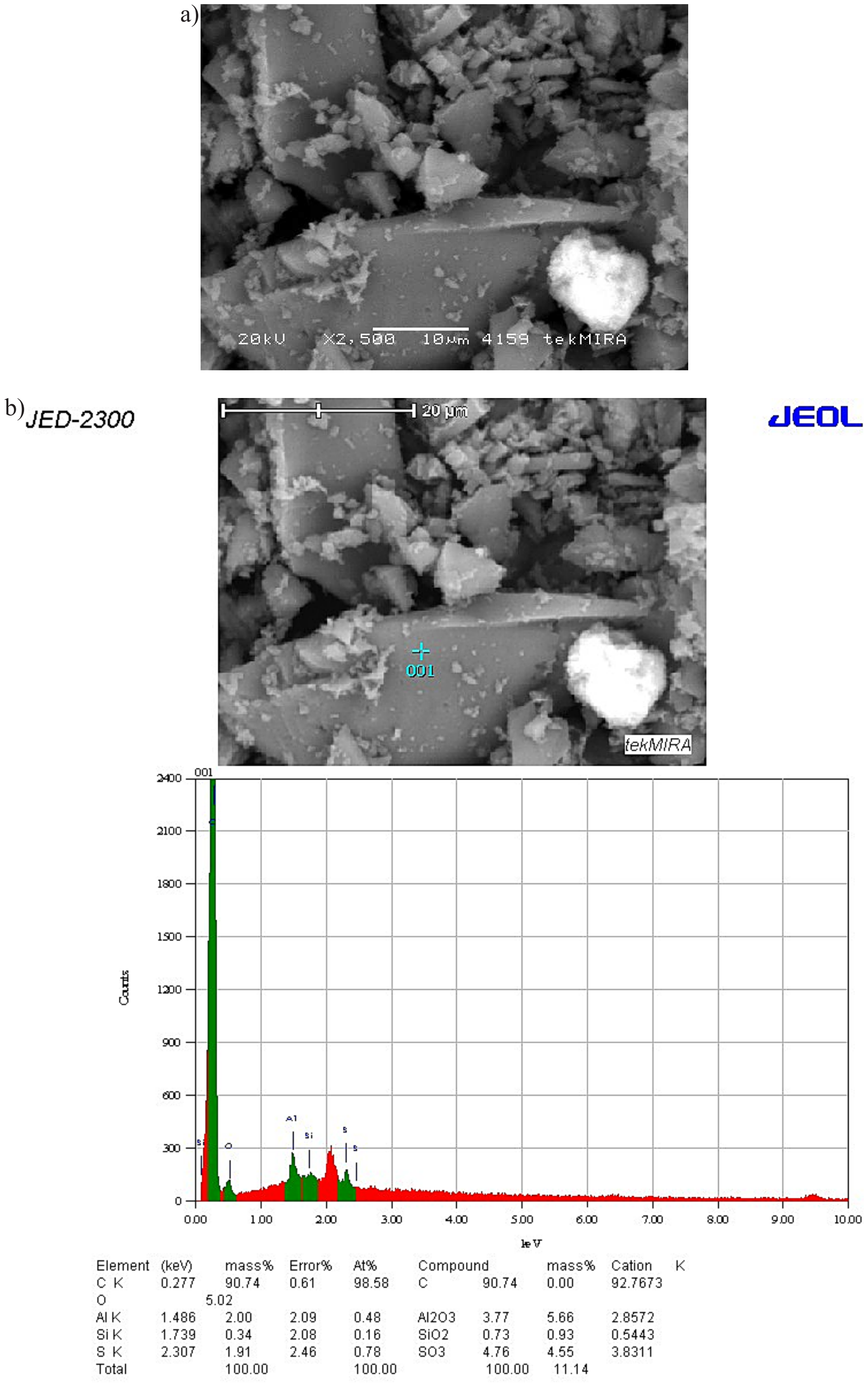
The sulfur content in charcoalwas relatively small assulfur in coal exists in three forms, namely pyrite $FeS_2$, where it is heated in an oxidizing atmosphere and transforms into iron oxide $Fe_2O_3$ while releasing $SO_2$ (Moloko and Van Der Merwe, 2021). The sulfur compounds in coal will be very detrimental because they will cause corrosion and pollution of $SO_2$and $SO_3$ in the atmosphere (Jančauskas and Buinevičius, 2021; Yang et al., 2021).

**Table 2.** Ultimate analysis of char products from low-rank coal

| Sample | Carbon | Hydrogen | Sulfur | Oxygen |
|---|---|---|---|---|
| Coal (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 |
| Coal (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 |

## Char product quality analysis of the results of the gasification process with SEM-EDS

The characteristic of charcoal from the gasification process was done by SEM-EDS analysis presented in Figure 3. The surface of charcoal is rough and has a large amount of porous structure. The surface of the charcoal is also dense, with some mineral particles embedded in the surface of the coal charcoal particles. The charcoal matrix releases a large amount of volatile matter and destroys many pores due to gasification. The



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Element  (keV)     mass%   Error%   At%     Compound         mass%   Cation   K
C  K     0.277     90.74   0.61     98.58   C         90.74  0.00    92.7673
O                5.02
Al K     1.486     2.00    2.09     0.48    Al2O3     3.77   5.66    2.8572
Si K     1.739     0.34    2.08     0.16    SiO2      0.73   0.93    0.5443
S  K     2.307     1.91    2.46     0.78    SO3       4.76   4.55    3.8311
Total              100.00           100.00             100.00  11.14
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Sample code:G467 J; Mag.: 2,500 x; Acc. volt.: 20 kV; Vac. mode: LV; Signal: BEC

**Figure 3.** Surface morphology (a) and elemental composition (b) of charcoal from gasification process

**Table 3.** Fuel ratio calculation and gray king assay analysis

| Sample | Ash | Volatile matters | Fixed carbon | Char/ coke type | Upgrading Result | |
|---|---|---|---|---|---|---|
| | | | | | Fuel ratio | Upgrading category |
| Coal 4600 kcal/kg | 1.96 | 42.06 | 45 | A | 1.07 | lignite-bituminous high volatile |
| Weight (5 kg) | 2.9 | 10.29 | 79.84 | A | 7.76 | semi bituminous-semi anthracite |
| Weight (7kg + WCO) | 2.22 | 7.72 | 83.7 | A | 10.84 | semi anthracite - anthracite |
| Coal 5000 cal/kg | 2.72 | 42.14 | 44.22 | A | 1.05 | lignite-bituminous high volatile |
| Weight (5 kg) | 6.64 | 6.2 | 80.86 | A | 13.04 | semi anthracite - anthracite |
| Weight (7 kg) | 6.08 | 6.66 | 82.08 | A | 12.32 | semi anthracite - anthracite |
| Weight (7 kg + WCO) | 8.8 | 5.72 | 77.4 | A | 13.53 | semi anthracite - anthracite |
| Method | ASTM D.3174 | ASTM D.3175 | ASTM D.3172 | BS 1016 | | |

result revealed that carbon is the main componentof charcoal (98.58%). The remaining content of charcoal consists of Al, Si, and S.

### Coal upgrading quality (fuel ratio calculation)

The raw material for coal of 4600 and 5000 kcal/kg is the lignite-bituminous high volatile. The coal grade rose to semi-anthracite when upgrading with the gasification process, 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, and spentwaste cooking oil can raise the LRC coal grade from semi-anthracite to anthracite (Table 3). Increasing the calorific value of coal, classified from 4600 to 5000 kcal/kg, produces a better fuel ratio. The grade achieved is semi-anthracite, but the influence of waste cooking oil is very small on the fuel ratio, only in the range of 12.32–13.53.

## CONCLUSIONS

The results showed that the gasification process could raise the grade of low-rank coal into char products with semi-anthracite to anthracite grades, where the fuel ratio reached 10.84. The carbon content of the charcoal from low-rank coal reached 98.58%, and the remaining inorganic elements in the product are less than 1.5%. Increasing the calorific value of coal, classified from 4600 to 5000 kcal/kg, produced a better fuel ratio with the grade achieved is semi–anthracite. The effect of waste cooking oil on the fuel ratio is quite small, in the range of 12.32–13.53.

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