Correlation of fixed carbon content and calorific value of South Sulawesi Coal, Indonesia

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Abstract. This study aims to correlate fixed carbon content using proximate analysis and calorific value analysis of the South Sulawesi Mallawa Formation coal. The study was conducted at two locations, namely in the Massenrengpulu Region of Bone Regency and Pujananting Region in Barru Regency. The research method used is the collection of field data each using the channel sampling method (ply by ply), which represents the lower layer, middle layer and upper layer. Then a proximate analysis is performed to obtain a fixed carbon content and an analysis of the calorific value. The results of the analysis show that, coal in the Pujananting area shows a correlation between the percentage of fixed carbon and the calorific value has a very good correlation with the linear regression value of 0.9994. Similar to the Mallawa Formation coal in the Massenrengpulu area, the correlation of fixed carbon content and calorific value shows a very good correlation with a linear regression value of 0.9998. An increase in the percentage of fixed carbon in coal will be followed by an increase of calorific value. This increasingly shows a very strong correlation between fixed carbon content and calorific value in coal.

1. Introduction
Coal is an organic sediment that consists of vegetation material, with the differences in composition between humic and sapropelic coal where humic types are far more frequent than sapropelic types [1]. Meanwhile, according to [2], coal is a combustible sedimentary rock, whose composition consists of a mixture of plant materials.

The coalification stage is a combination of biological, chemical, and physical processes that occur due to the influence of the loading of sediments covering it, temperature, pressure, and time on the organic components of peat [3]. Coalification process is the process of development of peat then lignite, sub-bituminous, bituminous into anthracite and anthracite meta due to pressure, burial and temperature. The degree of transformation or coalification is often called the rank of coal [3]. On this stage the percentage of carbon will increase, while the percentage of hydrogen and oxygen will decrease [4].

Classification of high rank Bituminous Coal and Anthracite based on different parameters [3] on Table 1 shows that the amount of carbon will increase with increasing rank of coal. Likewise, the number of calories contained in coal will increase along with the increasing rank in coal.

Coal deposits in Indonesia were found in some islands, such as Sumatra, Kalimantan, Java, Sulawesi, and Papua. Almost all of these coals have different qualities, chemical compositions and physical properties. The aims of this study is to explore the quality, chemical and physical properties of coal in Indonesia, especially South Sulawesi Coals.
Coal in the Mallawa Formation (South Sulawesi Coal) is generally has a high calorific value and qualifies for fuel. However, its utilization is not optimal due to the high sulfur content, which is above two percent [5–8]. The calorific value of the Mallawa Formation Coal ranges from 4900 to 6700 cal/gram [6]. Some studies of Indonesian coal characteristics, especially in Kalimantan have also been conducted by some authors [9,10].

![Classification of high rank Bituminous Coal and Anthracite based on different parameters](image)

**Figure 1.** Classification of high rank Bituminous Coal and Anthracite based on different parameters [3]

### 2. Methods

The study area is located in the Massenrengpulu Region of Bone Regency and Salopuru Region in Barru Regency (Figure 2). Stratigraphically, the constituent rocks included in the two regions are included in the Mallawa Formation.

The research method used is that researchers take coal samples directly from each field using the channel sampling method (ply by ply), which represents the lower layer, middle layer and upper layer. The research data was taken directly from the field in coal from the Mallawa Region of the Barru Region and the Bone Region (Figure 2).

Proximate analysis aims to obtain data on the characteristics of coal including knowing the solid carbon content in coal. Proximate analysis was conducted at the Processing and Analysis Laboratory of the Hasanuddin University Faculty of Engineering.

Coal sample preparation for proximate analysis includes several operations consisting of drying, grain size reduction, mixing, division and smoothing of the sample. The drying of the sample is carried out to obtain certain conditions so that it can be ground, and the distribution of the sample without losing weight or contamination. To find out the value of the content of solid carbon, first also need to know the moisture content, ash content, and the content of volatile matter. Fixed carbon content is calculated from 100% reduced by moisture content, ash content and volatile matter (ASTM D3173) [16]. The reduced moisture content means that the fixed carbon is higher.
Fixed Carbon = 100% – (moisture content % - Ash content % – volatiles %).

![Geological map and location of the study](image)

**Figure 2.** Geological map and location of the study

The percentage of moisture content is measured by using the dry oven method. At first the sample with a known weight was stored in an oven at 105°C for one hour and then weighed [11]. The moisture content of the sample is calculated using the following formula:

\[
M(\%) = \frac{W2 - W3}{W2 - W1} \times 100\% \quad \text{(1)}
\]

Which is

\[
W1 = \text{Weight of crucible (g)}
\]
\[
W2 = \text{Weight of crucible + sample (g)}
\]
\[
W3 = \text{Weight of crucible + sample, after drying (g)}
\]

Ash content was also determined by heating 2 grams of coal samples in a furnace at 550 °C for 4 hours and weighed after being cooled in a dessicator to obtain ash weight. The percentage of ash content is determined using the following equation:

\[
A(\%) = \frac{C}{A} \times 100\% \quad \text{(2)}
\]

The percentage of volatile matter is determined by crushing 2g of the briquette sample in a container and placing it in an oven until a constant weight is obtained then heated in a furnace at 550 °C for 10 minutes and weighed after being cooled in a dessicator. PVM is then calculated using the following equation:
Where: $A$ is the weight of the oven-dried sample (g) 

$B$ is the weight of sample after 10 min in the furnace at 550°C (g)

Analysis of the caloric value is determined using a bomb calorimeter. The working principle of this tool is to read the temperature or temperature of water from the combustion of coal. Calorie measurement through several stages or work procedures. First of all, 0.5–1 grams of sample is weighed, for the sample to be skewed first (mass of sample) weighed by wire (nickel) around 4 cm (mass of wire) and yarn around 15 cm (mass of thread). About 1 gram of the benzoic acid whose caloric value has been weighed for calibration, calibration tools that use benzoic acid are inserted into the camber and then tied with a thread connected to the nickel wire. A camber containing benzoic acid is put into a bomb vessel, filled with a maximum of 25 bar oxygen then put a bomb vessel in a water jacket containing 2 liters of distilled water. The water jacket is inserted into the calorimeter bomb, the calorimeter bomb and the digital bomb calorimeter are connected to electricity and turned on. After the reading on the digital bomb calorimeter shows 0.00 then press fire, note the reading of the instrument at intervals of 3 minutes until the reading of the device again decreases by about 2 reading points. Off the tool then the bomb vessel and oxygen remaining in the bomb tassel are removed.

3. Result and Discussion

The results of research conducted in the Massenrengpulu Region showed that the value of fixed carbon in the lower layer M-01 was 47.38% and then increased in the middle layer i.e. the M-02 sample to 51.67% and decreased again in the upper layer M-03 which was 49.03%. While the calorific value in the Massenrengpulu coal in the lower coal layer M-01 6652.76 cal / gram, in the middle coal layer shows the calorific value increased to 6700.26 cal / gram, while in the coal layer the upper layer M-03 calorific value decreased again to 6670.6 cal / gram.

The results of research conducted in the Pujananting Area showed the value of fixed carbon starting at the bottom layer P-01 was 32.3%, then increased in the middle layer i.e in the P-02 sample to 39.66%, and decreased again in the upper layer P-03 which is 36.77%. While the calorific value in the Pujananting Region coal at the bottom coal layer P-01 4900.89 cal / gram, in the middle coal layer shows the calorific value increased to 5450.20 cal / gram, while at the upper layer coal layer P-03 value calories decreased again to 5225.96 cal / gram.

The value of fixed carbon and calorific value in Massenrengpulu coal, Bone Regency and in Pujananting Barru Regency coal can be seen in table 2. The description above shows that the increase and decrease in fixed carbon value is also followed by an increase and decrease in calorific value. The relationship between fix carbon and the calorific value of the Massenengulu region is depicted on the graph of the linear regression equation (Figure 3).

The graph of the linear regression equation in Figure 3 shows the correlation between the value of fixed carbon and the calorific value in the coal of the Massenrengpulu Region. The graph of linear regression equation above shows the value of $R^2 = 0.9998$, which means it also shows that the value of fixed carbon and calorific values have a very strong correlation.

The relationship between fixed carbon and the calorific value of the Pujananting Region is depicted on the graph of the linear regression equation (Figure 4).
Table 1. Fixed Carbon and Calorific Value of coal in the Massenrengpulu Region in Bone Regency and Pujananting Region in Barru Regency.

| Sampling location | Samples of coal | Fixed carbon content (%) | Calorific value cal/gram |
|-------------------|-----------------|--------------------------|-------------------------|
| Massenrengpulu    | M.03 (upper seam) | 47.38                    | 6652.76                 |
|                   | M.02 (middle seam) | 51.67                    | 6700.26                 |
|                   | M.01 (lower seam)  | 49.03                    | 6670.6                  |
| Pujananting       | P.03 (upper seam)  | 36.77                    | 5225.96                 |
|                   | P.02 (middle seam) | 39.66                    | 5450.20                 |
|                   | P.01 (Lower seam)  | 32.3                     | 4900.89                 |

Figure 3. Linear regression graph showing the correlation of fixed carbon and calorific value of Massenrengpulu coal
Figure 4. Linear regression graph showing correlation of fixed carbon and calorific value of Pujananting coal

The graph of the regression equation in Figure 3 shows the value of $R^2 = 0.9994$, which means that the fixed carbon value and the calorific value have a very strong positive correlation. Every time there is an increase in the value of fixed carbon in coal, it will be accompanied by an increase in its calorific value.

4. Conclusion

The results of the study show that, coal in the Pujananting area shows a correlation between the percentage of fixed carbon and the calorific value has a very strong correlation with the linear regression value of $(R^2) 0.9994$ (nearing 1.000). Similar to the Mallawa Formation coal in the Massenrengpulu area, the correlation of fixed carbon content and calorific value shows a very good correlation with a linear regression value of $(R^2) 0.9998$ (nearing 1.000). An increase in the percentage of fixed carbon in coal will be followed by an increase of calorific value. This increasingly shows a very strong correlation between fixed carbon content and calorific value in the studied coal.

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