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Density Log Correlation with Coal Proximate in the Muaraenim Formation, Musi Banyuasin, South Sumatera

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Abstract:
This research was conducted in the PT BSPC area using the well logging method as the initial step in coal exploration activities. There are 7 well logging data sets with coal quality parameters including moisture content, ash content, and calorific value. From the processing and interpretation using WellCAD 5.7 software, the lithology of the study area consists of claystone, siltstone, sandstone, carbonaceous clay, and coal. At 7 points, 9 coal seams were identified, namely seams A11, A1, A, B11, B1, B, C, D1, and D. The thickest seam is seam B, with an average thickness of 5.85 meters. Correlation analysis shows that the relationship between density logs and proximate data is fairly strong, except for the calorific value, which does not correlate with the coal seam C in the study area. The most influential correlation to density values is moisture content. The quality of coal in seam B is better than that in seam C. On average, seam B has a calorific value of 5531 cal/g, whereas seam C is lower at 5153 cal/g. Both seams have relatively high ash content; however, seam B has a lower moisture content of 16.13%, compared to seam C's 16.65%

Keywords: coal, proximate, well logging.

1. Introduction

Coal is one of the fossil fuel types that significantly contributes to meeting the world's energy needs. In 2020, coal still accounted for 27% of the world's primary energy consumption. The largest coal consumption currently is held by Steam Power Plants (PLTU) as fuel to generate electricity. In addition, coal is also used as a heat source or reducer in various industries, such as cement, metallurgy, fertilizer, and textile industries. Specifically, for the metallurgical industry, the coal used is a special type called coking coal (Badan Geologi Kementerian ESDM, 2021).

The research is located in the coal-bearing formation, namely the Muara Enim Formation in the South Sumatra Basin (Gafoer et al., 1986). This study uses the well logging method as the initial stage of coal exploration activities. Geophysical well logging data is supported by geological data in the form of cuttings and coring, which can be correlated with one another to approach actual results. Through this correlation, it is possible to identify subsurface lithology vertically (Asquith et al., 2004).

There are many types of logs used in exploration, such as gamma ray logs, density logs, caliper logs, resistivity logs, spontaneous potential logs, neutron logs, and others. In coal exploration, the most conventional methods use gamma ray and density logs. The combination of these two logs can provide more detailed information, such as lithology type, coal seam thickness, and interbeds sandwiched between coal layers (Ardhityasari, 2017). Additionally, some combine gamma ray and resistivity logs to identify burnt coal near intrusions or coal that has been oxidized due to weathering. However, resistivity logs have limitations in determining coal seam thickness (Yulianto & Widodo, 2008).

In addition to identifying the presence of coal, further exploration is necessary through coal quality analysis. The characteristics of coal quality are very important in determining whether the coal deposit is feasible to be mined and in assessing the economic value of the coal itself. Coal quality refers to the classification of the physical and chemical properties of coal based on its potential and uses. The most fundamental test for coal quality is the proximate analysis (Permana, 2016). Proximate analysis provides the percentage by weight of fixed carbon, ash content, and moisture content in coal (Sepfitrah, 2016). In addition to proximate analysis, it is also very important to conduct calorific value testing on coal as a parameter of its thermal properties. This is done to determine the capability and potential for the use or conversion processes of coal. The density value of coal is influenced by its porosity. High porosity is often associated with lower coal quality because these pores can contain water, gas, or other impurities that can decrease the calorific value of coal (Budi & Yatini, 2021). In previous research (Karyadi & Setiawan, 2023), the study area was found to have coal quality ranging from lignite to sub-bituminous.

Therefore, research in this area is necessary to make the exploration and production stages more optimal and economical. This is because the exploration stage affects the quality and production of coal. The better the exploration stage, the better the quality and production of coal produced by a mining company. This study seeks to find the correlation between coal density and proximate data using statistical methods, specifically Pearson correlation.

2. Research Methods

The data for this study is secondary data obtained from geophysical exploration conducted by PT. Bhumi Sriwijaya Perdana Coal, specifically in the Muaraenim Formation (NMPM), Musi Banyuasin, South Sumatra (Figure 1). Coal exploration was carried out using the well logging method with gamma ray and density logs. Measurements were taken at 7 well points, namely MT-01 to MT-07. Data processing was performed using WellCad software to determine the lithology type obtained by reconciling cutting and coring data with logging data, thereby identifying the actual depth and thickness of the coal seams.

In addition to determining the depth and thickness of the coal layers, a correlation analysis was conducted between coal quality data in the form of proximate analysis and density logs. The correlation status is established based on Table 1. Quality analysis was performed on two seams, seam C and seam B, across the 7 well points. These two seams are present in all wells and represent different layer depths, with seam C being younger than seam B.

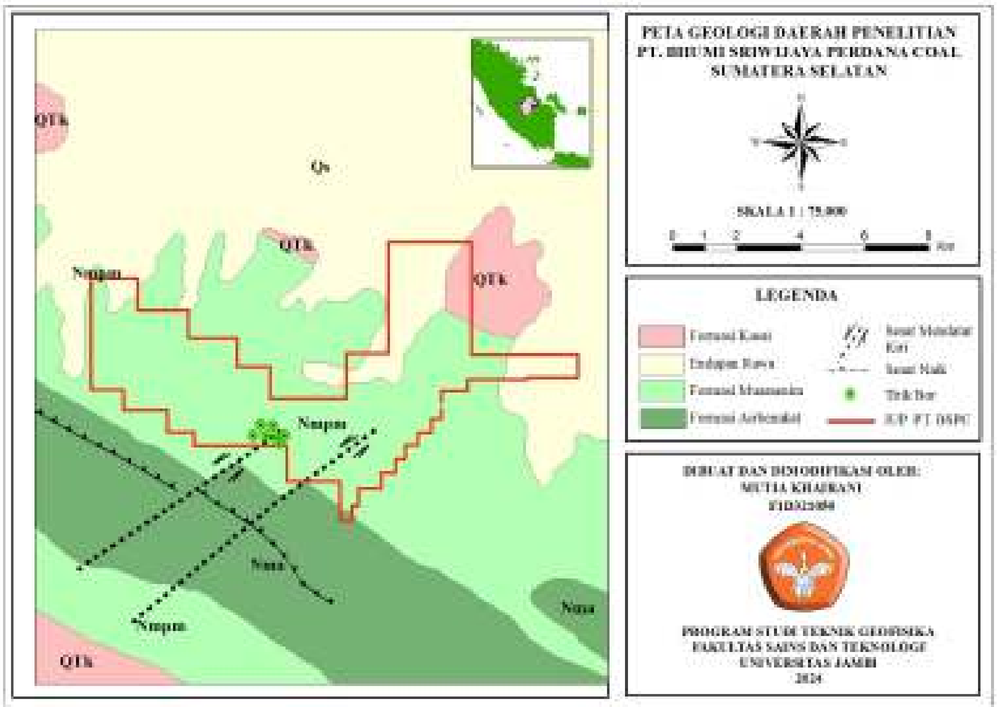

Figure 1. Regional geological map of the study area

Table 1. Linear correlation relationship between two variables (Sarwono, 2006)

Coefficient correlation (R^2)	Correlation
< 0.20	Correlation can be considered non-existent
0.20 - 0.40	Correlation exists but is low
0.40 - 0.70	Sufficient correlation
0.70 - 0.90	High correlation
0.90 - 1.00	Very high correlation

3. Results and Discussion

Analysis SEAM C

Seam C has an average thickness of only 1.14 meters and branches into seam C1 and seam C2. According to Table 2, this seam is classified as subbituminous C rank based on the ASTM – D388 table. The calorific value of coal depends on the process of how the coal was formed. In seam C, there is a parting layer of carbonaceous clay, and the presence of splitting phenomena indicates that this coal seam is dominated by non-carbon materials. This is evidenced by its ash content reaching up to 11.99% at well point MT-04.

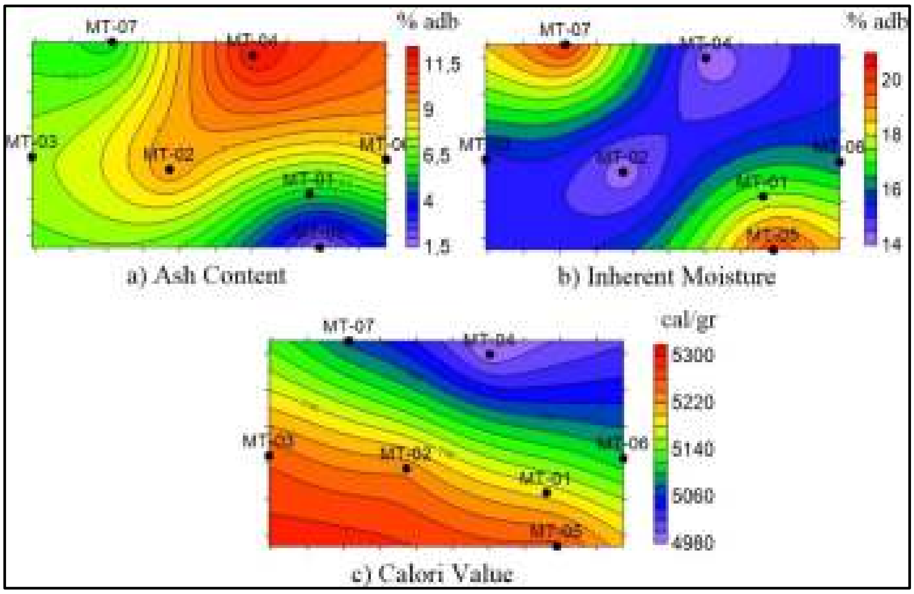

Figure 2. Distribution of quality of seam C

High ash content is located in the northeast area, indicated by orange to red colors, while the lower part, at point MT-05, has low ash content marked by blue color. Moderate ash content is indicated by green to yellow colors. The inherent moisture content in seam C tends to be low in 4 wells, whereas at MT-01, MT-05, and MT-07, the inherent moisture content is relatively moderate to high. The highest calorific values are found in the southwest area, while the lowest values are in the northeast. The calorific value correlates with ash content, where lower ash content corresponds to higher calorific value, and higher ash content corresponds to lower calorific value.

Table 2. Quality and rank of coal seam C

Spot	Seam	Thickness	CPS	g/cc	IM	Ash	CVADB	Ranking
MT-02	C	1.52	1997.29	1.49	14.11	9.47	5234	Subbituminous C
MT-03	C	0.69	2154.41	1.46	15.29	7.40	5254	Subbituminous C
MT-04	C	1.22	2285.46	1.43	14.18	11.99	4985	Subbituminous C
MT-05	C	0.9	3322.15	1.28	20.02	1.76	5267	Subbituminous C
MT-06	C	1.54	3290.26	1.28	16.08	8.49	5105	Subbituminous C
MT-07	C	1.02	2159.41	1.46	20.22	5.67	5073	Subbituminous C

The Relationship Between Density Log Values and Inherent Moisture, Ash Content and Calorific Value.

The correlation analysis between density and moisture in coal seam C indicates a fairly strong correlation with a tendency toward a negative regression direction, meaning that coal density and moisture content have an inverse relationship. Meanwhile, the coefficient of determination (r^2) is 0.16. This means that the density log value accounts for only 16% of the variation in inherent moisture content, while the remaining 84% is influenced by other factors. If the coal density increases, the moisture content in the coal will decrease accordingly. This aligns with the assumption that the higher the coal density, the lower the coal porosity, resulting in less moisture content because there are few or no pores or fractures to absorb or release water (Figure 3).

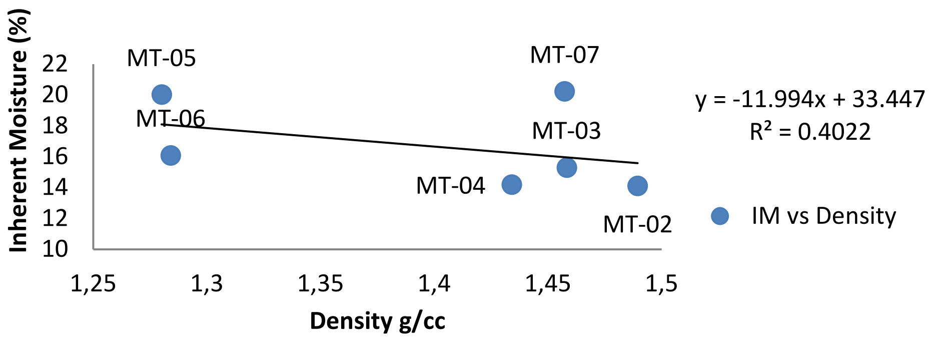

Figure 3. The relationship between density log values and inherent moisture

From the correlation analysis between density and ash content in coal seam C, with an average density of 1.4 g/cc and an average ash content of 7.46% adb, the correlation coefficient value r = 0.4838 indicates a strong correlation with a positive regression trend (Figure 4). The positive trend means that the higher the coal density, the higher the ash content, and vice versa.The coefficient of determination (r^2) is 0.23, which means that the density log accounts for only 23% of the variation in ash content, while the remaining 77% is influenced by other factors. Ash content in coal is the inorganic material that cannot be burned. The higher the ash content in coal, the poorer the coal quality. High ash content affects the efficiency of the combustion process and reduces the calorific value of the coal. Although the moisture content at MT-07 is high, the ash content is surprisingly low. It is suspected that there are significant minerals present that can increase the density but do not contribute to the combustion ash.

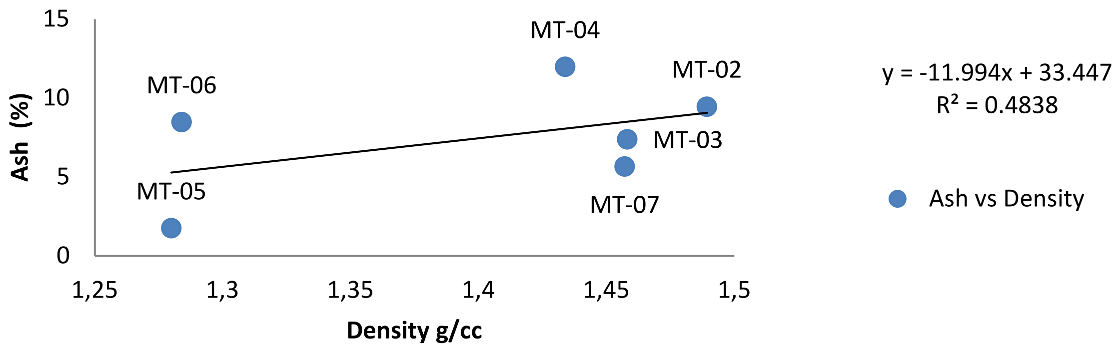

Figure 42. The relationship between density log values and ash content

As seen in Figure 5, there is no significant relationship between density and coal calorific value, with an average density of 1.4 g/cc and an average calorific value of 5153 cal/g and both values showed an inverse relationship. The low calorific value of coal can be caused by the high content of inorganic minerals in the coal, in this case, the high ash content in seam C. The coefficient of determination (r^2) is 0.009, meaning the density log accounts for less than 1% of the variation in coal calorific value. At MT-05, the calorific value is the highest compared to other points. This high calorific value is influenced by a very low ash content of only 1.79% adb, although the moisture content is relatively high at 20.02% adb. The density value based on the log is only 1.27 g/cc.

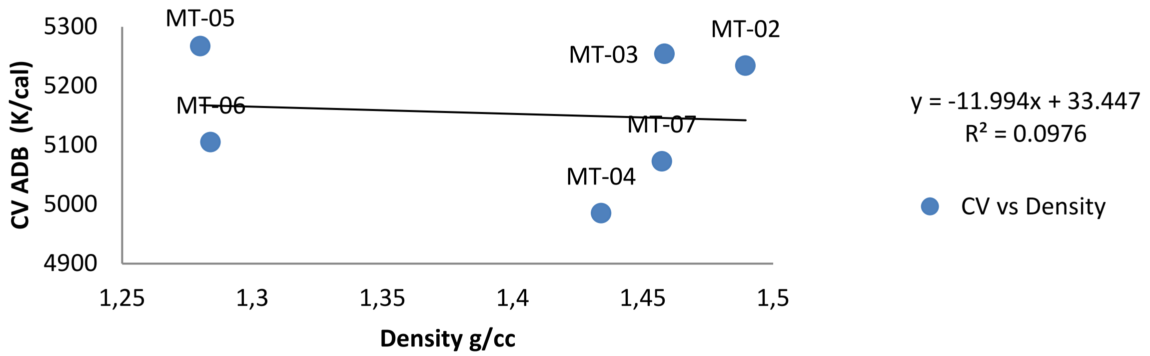

Figure 5. The relationship between density log values and calorific value

Analysis SEAM B

Seam B is the thickest coal seam in the study area, with an average thickness of 4.88 meters. This seam is also a single seam without any branching. Based on Table 2, this seam is classified as subbituminous B rank. The higher rank of coal in seam B compared to seam C is due to the absence of parting layers either before or after during the deposition of seam B. Additionally, seam B is much deeper and older than seam C, which also influences its rank (Figure 6).

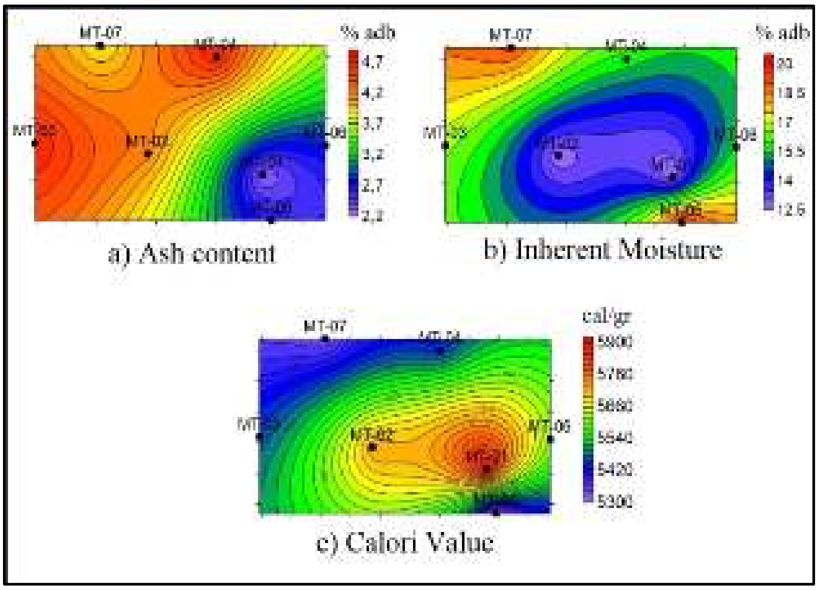

Figure 6. Distribution of quality of seam B

As seen in Figure 6, high ash content dominates the northwest area, indicated by orange to red colors, while low ash content is found in the southeast area, marked by blue color. For moisture content in this seam, low values dominate the central area and are nearly uniform in the regions marked by blue. High moisture content is found slightly in the upper northwest and lower southeast areas. The calorific value corresponds with the moisture content, where high calorific values dominate the central area with low inherent moisture, while low calorific values are associated with high moisture content.

Table 3. Quality and rank of coal seam B

TITIK	Seam	Thickness	g/cc	IM	Ash	CVADB	Ranking
MT-01	B	4.70	1.42	12.67	2,28	5890	Subbituminous A
MT-02	B	4.76	1.45	12.65	4,24	5737	Subbituminous B
MT-03	B	4.75	1.44	16.68	4,71	5464	Subbituminous B
MT-04	B	5.85	1.44	15.81	4,69	5449	Subbituminous B
MT-05	B	4.60	1.31	19.79	2,69	5304	Subbituminous B
MT-06	B	4.65	1.43	19.17	3,86	5339	Subbituminous B

The Relationship Between Density Log Values and Inherent Moisture, Ash Content and Calorific Value.

Density and moisture in coal seam B, with an average density of 1.41 g/cc and an average moisture content of 16.13% adb, a correlation coefficient of $r = 0.5898$ was obtained, indicating a moderate correlation with a negative regression trend (Figure 7). This means that coal density and moisture content have an inverse relationship. The density log accounts for only 34% of the variation in inherent moisture content, while the remaining 66% is influenced by other factors. In this seam, the MT-07 point has a relatively high moisture content of about 19.07% adb. This is similar to seam C, where MT-07 is an anomaly in the correlation between moisture content and density values.

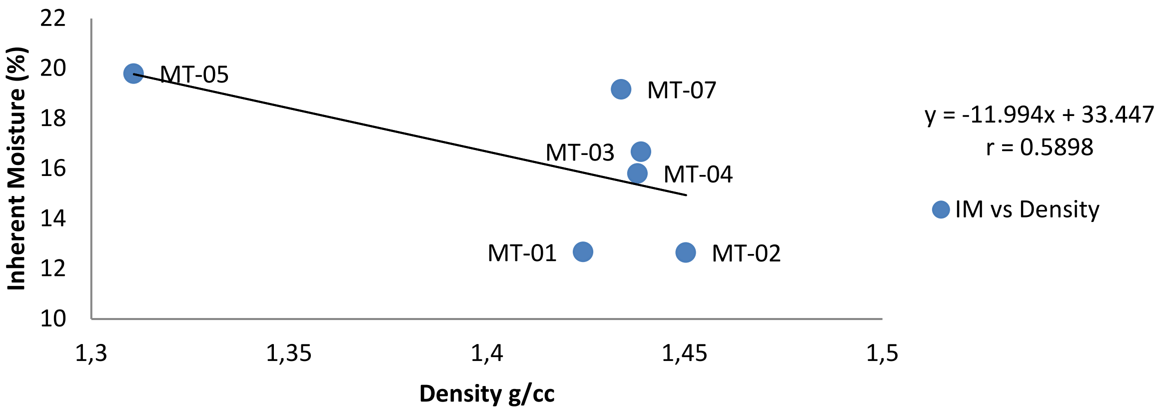

Figure 73. The relationship between density log values and inherent moisture

The relationship between density and ash content in coal seam B shows an average density value of 1.41 g/cc and an average ash content of 9.98% adb. The correlation coefficient $r = 0.5955$ indicates a moderate correlation with a positive regression trend (Figure 8). This means that the higher the coal density, the higher the ash content, and vice versa. The coefficient of determination (r^2) is 0.35, meaning that the density log accounts for only 35% of the variation in ash content, while the remaining 65% is influenced by other factors.

Ash content in coal is the inorganic material that cannot be burned. The higher the ash content, the poorer the coal quality. High ash content affects the efficiency of the combustion process and reduces the calorific value of coal. At point MT-01, the ash content is very low, but the density is relatively high at around 1.42 g/cc. The moisture content at this point is also very low, about 12.67% adb. This is a case where the density is high despite having low moisture and ash contents

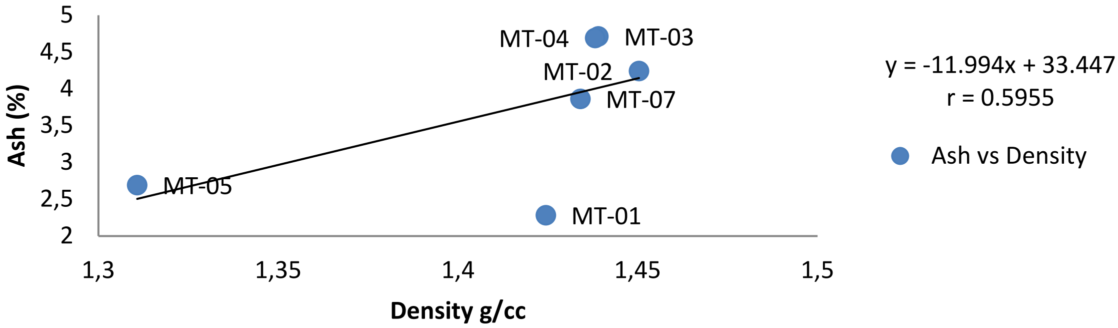

Figure 8. The graph of the relationship between density log values and ash content

The correlation between density and coal calorific value yielded a correlation coefficient of r = 0.4464, indicating a moderate correlation, with an average density of 1.41 g/cc and an average calorific value of 5531 cal/g. The correlation coefficient between density and calorific value is positive, meaning the two variables have a direct relationship. The coefficient of determination (r^2) is 0.19, which means that the density log accounts for only 19% of the variation in calorific value, while the remaining 81% is influenced by other factors. The low calorific value of coal can be caused by the high content of inorganic minerals in the coal, in this case, the high ash content in seam B.

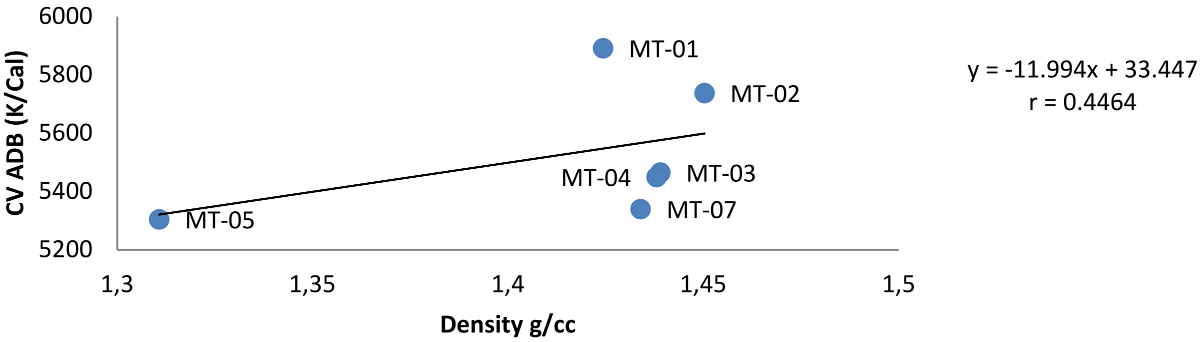

Figure 9. The graph of the relationship between density log values and calorific value

Previously, point MT-01 had low moisture and ash content, but it also showed the highest calorific value. A good calorific value indicates low moisture and ash content. Assuming that the higher the density value, the higher the calorific value, the density value at this point is consistent with that assumption. Other factors that can increase the calorific value are the organic components of coal, namely high carbon, oxygen, and hydrogen content.

4. Conclusion

Based on the correlation values, the parameters from the density analysis using log data and proximate data show a moderate correlation, except for the calorific value, which has no correlation with coal seam C in the study area. The parameter most strongly correlated with density is moisture content. According to theory, ash content is expected to have an inverse relationship with density; however, this does not apply to lignite to subbituminous coals, especially those with parting layers. The coal quality of seam B is better than that of seam C. On average, seam B has a calorific value of 5531 cal/g, while seam C is lower at 5153 cal/g. Both seams have relatively high ash content, but seam B has a lower moisture content of 16.13%, compared to 16.65% for seam C.

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