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Materials Science and Engineering 1173 (2021) 012010 IOP Publishing

doi:10.1088/1757-899X/1173/1/012010 1 Coal velocity and proximate analysis relationship

using Multiple Linear Regression S Erfani, F M S Siregar, A Zaenudin, Rustadi, I B S Yogi, and

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Lampung, Jalan Prof. Dr. Soemantri Brodjonegoro No. 1 Bandar Lampung 35145, Indonesia

*Email: rahmat.caturwibowo@eng.unila.ac.id Abstract. Coal properties such a velocity (V_p)

are essential to building a lateral distribution of coal seam using seismic data. The

experimental determination of velocity analysis is sophisticated, long time consumed, and

expensive. On the contrary, statistical approaches such as linear regression can be run

rapidly. The study's two main objectives were to develop models for coal velocity using

well log data variables (density and natural Gamma-Ray) and found the relationship

between velocity with proximate analysis results. Multiple linear regression (MLR) methods

were applied to estimate V_p 's relationship between estimated and proximate analysis. By

conducting cross-validation, the prediction analysis of the models has been tested by using

R2. The result showed that between V_p estimated versus V_p log have R^2 0.80 and V_p estimated versus proximate analysis that reflected have R^2 of 0.52. Correlations can estimate the relationship between V_p and proximate analysis, then applied that correlation to distributed in seismic volume to obtain coal seam characteristic. Keywords: velocity, coal, multiple linear regression, proximate, prediction

1. Introduction

The use of geophysical parameters to explore coal basins and delineate coal seams and geological structures that affect coal deposits is now widely practiced. Since the oil crisis in 1973, geophysical methods have increasingly been used to identify coal deposits by estimating coal targets that have economic value [1]. Several techniques have been used in oil and gas exploration and adapted for coal exploration purposes. This study uses the geophysical method, namely geophysical logging, to determine the relationship between its characteristics and the coal seam's proximate value. Coal as a lithology responds well to the most geophysical method in that its physical properties contrast with those of other lithologies commonly found in coal-bearing sequences. In general, coal has a lower density, a lower seismic velocity, a lower magnetic susceptibility, a higher electrical resistivity, and low radioactivity compared with surrounding rocks in typical coal-bearing sequences [1]. Density measurements of rocks are not usually measured in-situ but in the laboratory on some small outcrop or drill core samples. Singh and Dubey conducted previous research (2000) [2] where the value of the P wave was used to determine the effect of minerals from sandstones where the higher the P-wave, the values of uniaxial compressive strength (UCS), Young's Modulus (E), and density as well. However, IC-STAR 2020 IOP Conf. Series: Materials Science and Engineering 1173 (2021) 012010 IOP Publishing doi:10.1088/1757-899X/1173/1/012010 2 the value of P-wave velocity (V_p) is inversely proportional [3]. In the research carried out, taking one of the equations is looking for the V_p value to be used in estimating the relationship with proximate analyses. This research aimed to approach to predict the quality of the distribution of coal seams in a coalfield. Geophysical logging is the measurement of the variation with depth of particular physical properties of surrounding rocks with geophysical measuring tools (probes) located

in boreholes. Measurements are made by lowering a probe attached to the end of a cable to the bottom of the borehole and then raising the probe back out of the borehole at a constant rate to record the geology. In coal exploration, density logs are useful in identifying coal because coal has a lower density value than other lithologies such as shale and sandstone [4].

2. Methods

One of the methods that can be applied in predicting the distribution of coal quality is statistical approaches. This approach has been carried out by many researchers, one of them is Singh and Dubey (2000) [2], where they conducted experiments by calculating the value of the P wave, which is used to determine the effect of minerals from sandstones where the higher the P-wave, the uniaxial strength values, Compressive (UCS), Young's modulus (E). From some of the resulting equations, this study refers to the research that has been done by taking one of the equations, namely looking for the value of Vp. Where the empirical equation is given is: $V = 0.0009d$. (1) The Vp value of the density log data is based on the well log measurement results to find the Vp value from the sonic log based on multiple regressions and will be correlated with the sonic log of the well log results. Vp values are correlated with proximate data to determine the relationship between these values and existing concepts. The empirical formula given can be used to determine the quality distribution of the wells measured (Table 1). The regression calculations carried out sequentially is to find the correlation value between the Sonic logs calculated from the empirical formula with the velocity well log (Vp cal vs Vp log) to validate the Vp calculated (Vp cal), then correlating the Sonic logs calculated from the proximate data, namely Vp cal vs Ash, Vp cal vs Inherent Moisture, Vp cal vs Volatile Matter and Vp cal vs Fixed Carbon.

3. Results and Discussions

3.1. Calculated Vp calculated vs. Vp well log

The calculation and graph in Figure 1 obtained an excellent relationship between the two regressed variables, which indicates that the two variables have a directly proportional relationship. This means that the velocity calculation (Vp cal) results are as good as the well log results with a correlation of 80%.

3.2 Ash vs. Vp calculated

Ash is a residual material that remains during the coal combustion process with specific conditions where the main elements are oxides and sulfates. Based on the calculation results (Figure

2), the relationship between Ash vs. Vp is inversely proportional, which means it explains that the higher the Ash content, the lower the velocity value and vice versa. This is not following the concept. The higher the value of ash content, the higher the Vp response. An example is lignite coal, which has a high ash content value tends to have a high sonic response compared to the Vp value of anthracite coal. IC-STAR 2020 IOP Conf. Series:

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doi:10.1088/1757-899X/1173/1/012010 3 Figure 1. Relation of Vp calculated vs. Vp well log.

Table 1. Coal data (velocity, density, and proximate analysis) were used in this study

Sample Number	Density core (g/cm ³)	Density (g/cm ³)	Vp (m/s)	Vp (m/s)	Ash (%)	IM (%)	VM (%)	FC (%)
1	1.2	1.30	0.00050	0.0012	2.6	14.4	39.4	45.0
2	1.2	1.40	0.00050	0.0013	2.6	14.8	39.8	46.6
3	1.17	1.29	0.00050	0.0012	1.3	13.8	39.4	42.4
4	1.23	1.33	0.00050	0.0012	5.0	13.4	41.9	43.8
5	1.25	1.28	0.00050	0.0012	9.8	12.3	40.6	36.9
6	1.18	1.27	0.00050	0.0011	2.9	12.6	40	46.9
7	1.18	1.25	0.00050	0.0011	3.2	13.0	42.6	43.9
8	1.21	1.33	0.00050	0.0012	3.8	11.8	41.2	43.5
9	1.21	1.31	0.00050	0.0012	3.4	10.2	38.8	32.9
10	1.26	1.30	0.00050	0.0012	6.6	11.6	39.8	43.3
11	1.24	1.29	0.00050	0.0012	6.6	7.7	41.1	41.5
12	1.29	1.28	0.00050	0.0012	14.3	8.2	43.6	41.3
13	1.21	1.27	0.00050	0.0011	2.3	10.8	43.6	38.0
14	1.27	1.24	0.00050	0.0011	2.1	11.4	40.7	37.1
15	1.24	1.24	0.00050	0.0011	3.8	11.5	41.6	42.8
16	1.3	1.25	0.00050	0.0011	9.3	9.0	42	41.8
17	1.28	1.50	0.00052	0.0014	7.7	15.48	39.2	33.93
18	1.32	1.36	0.00050	0.0012	2.9	14.42	28.36	39.8
19	1.46	1.45	0.00051	0.0013	1.4	15.98	39.04	37.26
20	1.28	1.43	0.00051	0.0013	3.4	16.34	39.18	39.0
21	1.3	1.35	0.00050	0.0012	4.6	16.4	38.74	41.43

IC-STAR 2020 IOP Conf. Series: Materials Science and Engineering 1173 (2021) 012010 IOP Publishing doi:10.1088/1757-899X/1173/1/012010 4 Figure 2. Relation of Ash vs. Vp calculated.

3.3. Inherent Moisture vs. Vp calculated Inherent Moisture (IM) is the amount of water contained in coal microspores. In other words, the value of IM is not affected by the amount of external water, such as formation water. IM values generally get lower as coal ranks rise. The IM value should directly proportional to the velocity value, namely, the higher the IM value, the higher the velocity value. This correlation is shown in

Figure 3. Figure 3. Relation of Inherent Moisture vs. Vp calculated. 3.4 Volatile Matter vs. Vp calculated As determined by standard test methods (i.e., ASTM D-3175; ISO 562), the volatile matter is the percentage of volatile product/material, i.e., water vapor that is released during the coal heating process from the graphic showed in Figure 4. The higher the Volatile value, the higher the product/material $R^2 = 0,0152$

00,00020,00040,00060,00080,0010,00120,00140,00160 2 4 6 8 10 12 14 16 $R^2 = 0,4741$

00,00020,00040,00060,00080,0010,00120,00140,00160 2 4 6 8 10 12 14 16 18 IC-STAR 2020

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doi:10.1088/1757-899X/1173/1/012010 5 contained in a coal sample. Velocity is directly

proportional to the Volatile Matter value. The higher the velocity response, the higher the

VM value should be. Figure 4. Relation of Volatile Matter vs. Vp calculated. 3.5 Fixed Carbon

vs. Vp calculated Fixed carbon is the remaining material after determining the test results of

moisture, volatile matter, and ash [4]. From the graph in Figure 5, we got the higher the

coal rank, the higher the Fixed Carbon value, and the lower velocity log response. The

results of the calculations show conformity to the concept where the correlation is inversely

proportional. Figure 5. Relation of Fixed Carbon vs. Vp calculated. The multiple regression

analysis results with the sonic value input data as the dependent variable (y) with proximate

values such as ash, inherent moisture, volatile matter, and fixed carbon as the independent

variable (x) as shown in Table 2. $R^2 = 0,1382$

00,00020,00040,00060,00080,0010,00120,00140,00160 10 20 30 40 50 $R^2 = 0,1001$

00,00020,00040,00060,00080,0010,00120,00140,00160 10 20 30 40 50 IC-STAR 2020 IOP

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doi:10.1088/1757-899X/1173/1/012010 6 Table 2. Multiple linear regression analysis results

between velocity (Vp calculated) and proximate analysis. Coefficients (10-5) Standard Error

(10-5) P-value R2 Intercept 112.590 27.507 0.001 X 1 1.049 0.498 0.051 0.520 X 2 2.307

0.668 0.003 X 3 -0.126 0.518 0.811 X 4 -0.541 0.373 0.166 The correlation degree R2 is

0.523 or 52.3%, where it could be said that the relationship between sonic responses to

proximate values has a strong enough relationship and influences each other. The standard

error of 0.00000062 indicates that the average data observed is excellent. It is close to the regression line. The P-value obtained from the analysis shows that the sonic variable (intercept = 0.00) and ($x_2 = 0.00$) shows a statistically significant variable. This variable is the content of Inherent Moisture (IM) statistically has a significant relationship with sonic value. Meanwhile, the proximate variables ash content, volatile matter and fixed carbon have a p-value of $x_1 = 0.005$, $x_3 = 0.81$ and $x_4 = 0.17$ indicates these variables are not statistically significant.

4. Conclusions Based on calculation results and multiple regression analysis, the empirical formula is sufficiently feasible to apply to coal seams. There are two correlation calculations following the concept of coal, namely the correlation between the Vp calculated from the empirical formula with the Vp log with a correlation degree of 0.80 indicates that Vp log computation with Vp log has almost no difference if applied especially if there is no log Vp data available, we can approach to calculate Vp by ourselves. The multiple linear regression analysis correlations are 0.52 (50%) that multiple regression analysis can be used as an alternative to log density in interpreting coal quality. It is hoped that the relationship between this approach's results can be applied to other cases with many data to estimate the distribution of coal quality. So it can be concluded that the log velocity value can be used to distribute quality properties in the coal seam.

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