Friday, September 30, 2022

GEOMATE Journal Review and Evaluation

Paper ID number

3624

Paper Title

EMPIRICAL ANALYSIS OF DENSITY VALUE BASED ON LABORATORY TEST AND GEOPHYSICAL LOG ON SEDIMENTARY ROCK

Originality

Good

Quality

Average

Relevance

Good

Presentation

Good

Recommendation

2. Accept with minor revision

General comments

the paper is good and able to accept. Minor revision is required to improve the quality of the paper.

Mandatory changes

The title needs to be simplified
What mean "CPS"

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Friday, October 14, 2022

GEOMATE Journal Review and Evaluation

Paper ID number	3624
Paper Title	EMPIRICAL ANALYSIS OF DENSITY VALUE BASED ON LABORATORY TEST AND GEOPHYSICAL LOG ON SEDIMENTARY ROCK
Originality	Average
Quality	Average
Relevance	Average
Presentation	Average
Recommendation	2. Accept with minor revision

General comments

1. The manuscript is showing that the experimental work is thoughtfully carried out.

Mandatory changes

The research significance is not clear with respect to the paper.
research gap is also not clear.
Include tabulation to compare the work with other wor and then prove how the study has contributed significantly
please take care of plagiarism as per the conference standards.

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Originality	Average
Quality	Average
Relevance	Average
Presentation	Poor
Recommendation	2. Accept with minor revision

General comments

Although I am not an expert in this field, I felt that the contents of the manuscript had an impact.

Mandatory changes

Fig.2
I wonder why X was not cps and Y was not g/cm3 from the first.
The given equation would be different from (2).

Suggested changes

See the attached file.

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International Journal of GEOMATE, Month, Year Vol.00, Issue 00, pp.000-000
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2022.000.0000
Geotechnique, Construction Materials and Environment

EMPIRICAL ANALYSIS OF DENSITY VALUE BASED ON LABORATORY TEST AND GEOPHYSICAL LOG ON SEDIMENTARY ROCK

*Supandi[1]

[1]Mining Engineering Department, Institut Teknologi Yogyakarta, Indonesia

*Corresponding Author, Received: 00 Oct. 2018, Revised: 00 Nov. 2018, Accepted: 00 Dec. 2018

ABSTRACT: Relationship model of counts per second (cps) and g/cm^3 has been widely spread, but verification of whether the equation applies to all rocks has not been carried out much. The equation that is widely used in determining the correlation is Warren equation. However, this equation needs to be verified to ensure whether it can be applied to all materials. This research aims to verify whether Warren equation can also be applied to clastic sedimentary rocks which have low mechanical properties. This research also seeks to explore the relationship between cps and g/cm^3 values in clastic sedimentary rocks. The variables in this research include density values resulted from laboratory testing and measurement result of geophysical logging inside bore holes. The density variable consists of wet density and dry density, while the geophysical log variable consists of long-spaced density (LSD) and short-spaced density (SSD). The analysis was carried out by using regression with heteroscedasticity-consistent standard errors. The result shows that Warren equation could not be applied to sedimentary case. Besides, the conversion models of cps to g/cm^3 for clastic sedimentary rocks that were built had low predictive ability. Therefore, determination of rock density is still recommended using laboratory tests of rock samples.

Keywords: Density, Count per second, gr/cm^3, Material properties

1. INTRODUCTION

In general, rock density is a ratio between the mass and the total volume of rock. There are five measurements of density, namely true density, apparent density, particle density, bulk density, and in-place density. True density is a division of the mass by the volume filled by free pores present in a solid. Precise determination of true density requires complete filling of the pore structure by a fluid that does not interact with the solid. Apparent density is determined by immersing the sample weight of a solid in a liquid followed by measuring the accuracy of the liquid being transferred (pycnometer method). Bulk density is the mass of a collection of solid particles in a container divided by the volume of the container. Density value depends on true density, particle size, size distribution, particle shape, surface water content, and degree of compactness. In-place density should be determined on a saturated sample to adjust for the balance of water content that presents under in-situ condition. In a simple manner, a rock has two components, solid component and pore component. The values of solid and pore components vary in each rock; therefore, density of a rock is different from density of the other rock.

Rock density is used in slope geometry design by finding the unit weight of each slope rock (lithology) to design safe slope; in constructing road by finding the material density to design road that can be passed by certain loads; and in selecting heavy equipment to carry out material excavation. Density correlates with depth, where the increase in depth leads to an increase in density due to the pressure of formation that causes a decrease in void in rock mass [1].

Geophysical well logging is a method of recording subsurface data inside a borehole by detecting radioactive signals in each rock. The method measures and records physical or lithological properties of formation at each depth. The continuously recorded data appear as wireline log which is used for investigating response to variation of rock physical properties in a borehole. Radioactive is the act of decomposing atomic nuclei spontaneously and emitting alpha particles, beta particles, or gamma radiation. The emitted ray is referred to as radioactive ray, while the substance emitting radioactive ray is referred to as radioactive substance.

Based on laboratory test, bulk density has strong negative relationship with neutron log value in coal [2]. When the bulk density (gr/cm^3) decreases, the neutron value will increase. Density log can be used to predict mechanical properties of rock, which include uniaxial compressive strength (UCS), friction angle, and cohesion [3]. This study has not considered whether the density log also has a strong correlation with physical properties, and the limitations of the material used in the analysis need to be further defined. The deeper the rock has an impact on increasing pressure [4,5]. Shear modulus, elastic modulus, and Poisson's ratio are also associated with depth as well as effective stress. This is closely related to density [6,7]. There is one interesting phenomenon in research on relative density of rocks, where the researchers [8] conveyed the result of the study that relative density of rocks (gr/cm^3) has a positive relationship with relative density of logging interpretation result (gr/cm^3) with a degree of 0.7617. Every increase in relative density based on lab test is always followed by an increase in relative density based on logging. Other studies have conveyed that log-based density and lab-based density have a negative relationship, where every increase in lab density value (g/cm^3) will be followed by a decrease in log density (cps – count per second).

A tool that makes use of radioactive ray source to measure density of rock is density log. It provides data of rock density along borehole, which can distinguish lithological type of rock. Porosity and the type of content therein, as well as rock compactness, have an impact on the values of rock density. This because porosity is influenced by rock compactness. The different levels of density and porosity are owned by coal and other overburden, resulting in log data that clearly looks different.

The working principle of a density log, according to [9], is that a radioactive source from a measuring device emits gamma rays passing through rock formation at a specific energy level, where the rocks are formed from mineral grains composed of atoms consisting of protons and electrons. Gamma ray particles strike the electrons in rocks, resulting in a collision which causes the gamma ray energy to drop. The rock density affects intensity of the reflected gamma ray, and then the detector in a specified distance from the source detects the energy that is released following the collision [10].

When the grains or minerals per volume are dense, which is indicated by a lot of electrons in the rock, the returned energy will be weak. Factors that influence the amount of energy received by the detector are:

1. Density of rock matrix
2. Rock porosity
3. Density of rock pores
4. Borehole diameter
5. Mud cake
6. Source-detector spaces: long-spaced density (LSD) or short-spaced density (SSD)

The distance between the radioactive source and the detector will affect the volume of rock investigated by the density log, so when the rock does not require high resolution, it can be used long-spaced density (LSD) [11]. There are two types of log density based on the source detector space (Fig.1), which are long-spaced density (LSD) and short-spaced density (SSD). The applications for LSD log and SSD log are as follows:

1. When evaluating subsurface, LSD log may be used due to the small influence on the borehole wall, so the resulting density value is relatively close to the actual value. The source distance is ± 16 inches.
2. When measuring the thickness of subsurface, SSD log may be used due to its vertical resolution that is higher than that of LSD Log. The source distance is ± 7 inches.

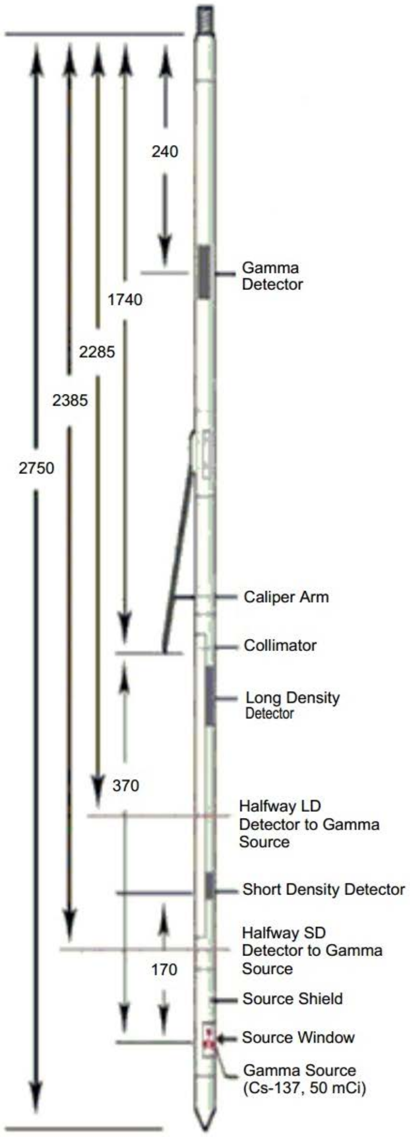

Fig.1 Long-spaced density (LSD) and short-spaced density (SSD) detectors [12]

In identifying evaporites, detecting gas zones, determining hydrocarbon density, and also monitoring shaly sand reservoirs and rock formations, geologists need density log [13]. The Eq. (1) is used to calculate porosity:

$$\Phi_{den} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (1)$$

where:
Φ_{den} = density value of porosity
ρ_{ma} = density of matrix or constant
ρ_b = density in a formation
ρ_f = density of fluid (1.1 for salty mud; 1.0 for fresh mud)

In this research, the unit of log density is counts per second (cps). The cps is a number of atoms detected in a material that decays per second. The unit can be calibrated from cps to g/cm^3 by using the model of cps and g/cm^3, known as Warren equation in Fig.2, cps has inversely proportional relationship with g/cm^3, where a high value in g/cm^3 unit leads to a low value in cps and vice versa. The relationship model is y = -2,370.9x + 6,945.4, where y is cps and x is g/cm^3. To determine the g/cm^3 value based on cps, the equation is modified into g/cm^3 as new y (y') and cps as new x (x') (Eq. (2)):

$$y' = \frac{6{,}945.4 - x'}{2{,}370.9} \qquad (2)$$

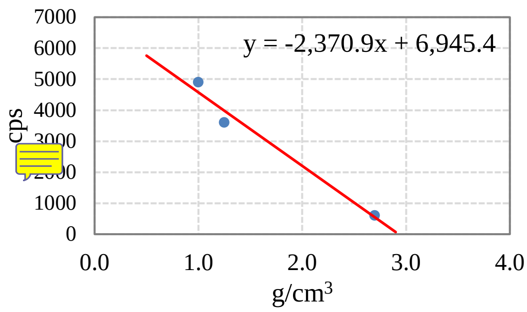

Fig.2 Warren equation is showing inversely proportional relationship between cps and g/cm^3

2. RESEARCH SIGNIFICANCE

Rock density serves a variety of purposes in science and engineering. Currently, determining the density is based on laboratory tests on rock samples. Obtaining samples of rocks distant from the earth's surface could be expensive and challenging, and geophysical method is expected to be able to provide an overview of the rock density. The geophysical method is relatively quick and accurate with a lower cost than that of core drilling method. This research may shed new light on optimizing geophysical logging whose utilization has not yet been optimized. This research may also help in estimating rock density for various purposes.

3. MATERIAL AND METHOD

Density test was carried out on samples of sedimentary rocks from drilling activity by following ASTM 792-20. The geotechnical drilling activity to sampling referred to ASTM D2113-99. Description of sedimentary rocks used ASTM D5434-97 and ASTM D2488-00. The lithology of research area is composed of sandstones which consists of fine to sandy quartz minerals [14] with a rupture angle of about 53° [15]. Claystone is composed of sand-sized quartz minerals with a few clay minerals in the form of kaolinite and illite [16]. Both of these rocks will experience deterioration when exposed, which degrades the physical and mechanical properties of the rock [17].

Geophysical logging was carried out in several boreholes in various depths. The locations were in a formation with the same geological characteristics. The logging was carried out with speed of 5 m/min after boreholes had been clean from mud from drilling activity. The logging speed of 5 m/min is the optimum speed to produce stable data quality on sedimentary rock [18]. Rock density was measured using GDDC (Gamma Dual Density and Caliper) type probe at both short-spaced density (SSD) and long-spaced density (LSD).

This research compares the density values from laboratory testing with the density values from geophysical logging inside boreholes. The unit of density based on laboratory testing is in gram per cubic centimeter (g/cm^3), while the unit of density based on geophysical logging is in counts per second (cps). Warren equation in Eq. (2) was verified by converting the unit of density from geophysical logging using the equation and then comparing it with the density from laboratory testing. The relationship of density values based on geophysical logging before converted and based on laboratory testing was also observed to determine the suitable conversion of cps to g/cm^3 in sedimentary rock by using regression analysis method. Referring to the Warren equation, the relationship was assumed to have linear pattern. This analysis ignores the lithology factor, but puts forward the measurement values both in laboratory and in field using geophysical log.

The equation of linear regression for determining relationship of density based on laboratory testing and density based on geophysical logging is (Eq. (3)):

$$Y = b_0 + b_1 X \qquad (3)$$

where Y is density obtained from laboratory testing, b_0 is regression constant, b_1 is regression coefficient, and X is density obtained from geophysical logging. For simple regression (only one X), the model proposed is considered to be significant, or in other word, the relationship between X and Y can be determined by the model proposed, when p-value resulted from t test statistics of regression coefficient is smaller than specified significance level, which is 5%.

The results of regression analysis can be erroneous when there is violation in the assumption of regression analysis. One of the assumptions that needs to be met is homoscedasticity, which means that there are equal variances in the conditional distribution of Y. In pre-analysis, the violation of it was found, called heteroscedasticity. This influences the validity of statistical inference in regression through its effects on the estimates of standard errors of regression coefficient [19]. One of the alternatives that Darlington and Hayes [19] is considered to deal with this situation is heteroscedasticity-consistent standard errors.

To know how well density based on geophysical log (X) in the sample model predicts density based on laboratory testing (Y) in the population, shrunken R (R_S) is used. R_S close to 1 means higher predictive ability [20].

4. RESULT AND DISCUSSION

Warren equation (Eq. (2)) for converting cps to g/cm^3 has been widely spread and believed to be true. This model equation has not been completely explained how it is built, what the limitations are, and whether the equation can be implemented for all variations of lithology or only for certain lithology. Value of g/cm^3 unit has a high sensitivity to its applications, such as in engineering, design, geotechnical, and other disciplines. So far, not many researchers have conducted empirical studies on how the equation is and whether it is valid for sedimentary rocks.

Density test in laboratory was carried out by measuring the wet and dry density in unit of g/cm^3. Meanwhile, geophysical measurement was carried out using short-spaced and long-spaced detectors which yield density data in unit of cps. There were 52 rock samples used for analysis. To verify the Warren equation (Eq. (2)), the density data obtained from geophysical log were converted using the equation and then compared with the density data obtained from laboratory testing. Visualization of the results is in Fig.3. The results show that the error of short-spaced density (SSD) conversion using Warren equation is much worse than the error of long-spaced density (LSD) conversion. In LSD conversion, the error ranges from 1.09% to 109.89% with average of 28.96% for wet density; while for dry density, the error ranges from 0.15% to 112.09% with average of 26.79%. In SSD conversion, the error ranges from 230.70% to 437.64% with average of 295.28% for wet density; while for dry density, the error ranges from 251.10% to 585.66% with average of 337.23%. Both conversions yield negative values, especially for SSD, all the results are negative.

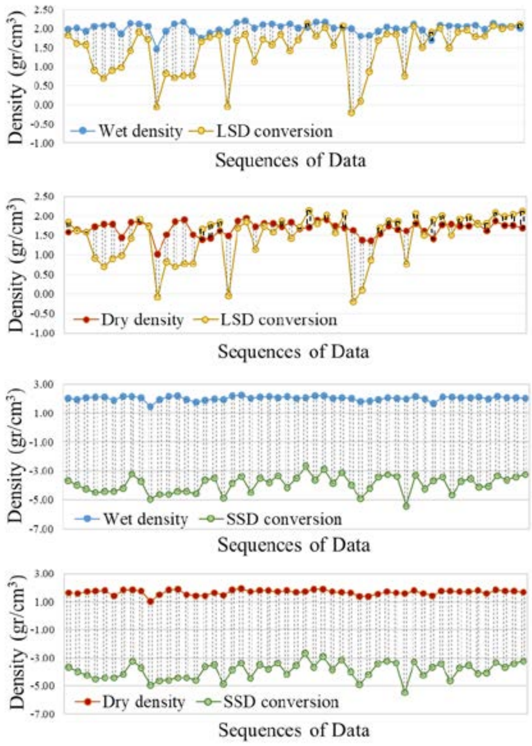

Fig.3 Comparison of wet and dry densities with conversions of long-spaced density (LSD) and short-spaced density (SSD) using Warren equation

Based on the verification result, the Warren equation is definitely not for this research data. Therefore, a new conversion model of cps to g/cm^3 was built using regression analysis. Since in pre-analysis, heteroscedasticity was found, analysis used regression method with heteroscedasticity-consistent standard errors. The results are in Table 1.

Most of the LSD values (80%) ranged from 2,000 to 3,500 cps, 15% were in range of 4,200 to 5,200 cps, and 5% in range of 6,750 to 7,500 cps. Wet density from laboratory test was in range of 17 to 2.2 g/cm^3 and only about 10% was below 1.7 g/cm^3. The relationship model of LSD and wet density is as follows:

$$\text{Wet density} = 2.147 - 3.76\times10^{-5}\ \text{LSD}$$

Table 1 Regression analysis result

LSD vs Wet Density					
	Estimation	Std. Error	t	p-value	R_S
Constant	2.147	0.065	32.840	0.000	-0.384
LSD	-3.76×10^{-5}	2.11×10^{-5}	-1.778	0.081	
LSD vs Dry Density					
	Estimation	Std. Error	t	p-value	R_S
Constant	1.864	0.077	24.247	0.000	-0.424
LSD	-5.37×10^{-5}	2.50×10^{-5}	-2.147	0.037	
SSD vs Wet Density					
	Estimation	Std. Error	t	p-value	R_S
Constant	2.645	0.257	10.285	0	-0.374
SSD	-3.88×10^{-5}	1.65×10^{-5}	-2.357	0.022	
SSD vs Dry Density					
	Estimation	Std. Error	t	p-value	R_S
Constant	2.528	0.323	7.821	0.000	-0.38814
SSD	-5.24×10^{-5}	2.07×10^{-5}	-2.531	0.015	

Based on the result in Table 1, the model is not significant, known from the p-value of 0.081 which is greater than significance level of 0.05. The R_S of -0.384 shows that the predictive ability is low. Meanwhile, dry density from laboratory test ranged from 1.5 to 2.0 g/cm^3 and <10% were below 1.5 g/cm^3. The relationship model of LSD and dry density is as follows:

$$\text{Dry density} = 1.864 - 3.88\times10^{-5}\ \text{LSD}$$

The p-value of 0.037 (Table 1) is smaller than significance level of 0.05; therefore, the model is significant. The R_S of -0.424 also shows that the predictive ability is low. Plot of LSD and wet density as well as dry density is presented in Fig.4 and Fig.5 respectively.

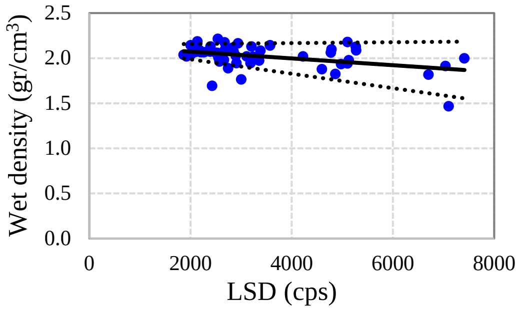

Fig.4 Plot of long-spaced density (LSD) and wet density

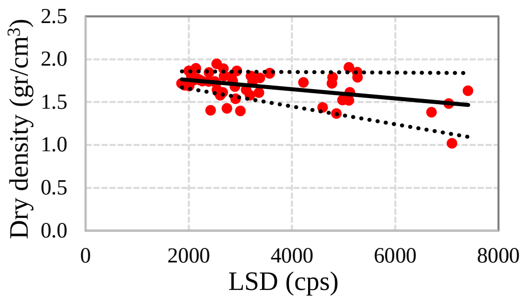

Fig.5 Plot of long-spaced density (LSD) and dry density

Most of the SSD values (80%) ranged from 14,500 to 18,000 cps and 10% were outside the range. The relationship model of SSD and wet density is as follows:

$$\text{Wet density} = 2.645 - 3.88\times10^{-5}\ \text{SSD}$$

Based on the result in Table 1, the model is significant, known from the p-value of 0.022 which is smaller than significance level of 0.05. The R_S of -0.374 shows that the predictive ability is low. For dry density, the relationship model with SSD is as follows:

$$\text{Dry density} = 2.528 - 5.24\times10^{-5}\ \text{SSD}$$

The p-value of 0.015 (Table 1) is smaller than significance level of 0.05; therefore, the model is significant. The R_S of -0.388 also shows that the predictive ability is low. Plot of SSD and wet density as well as dry density is presented in Fig.6 and Fig.7 respectively.

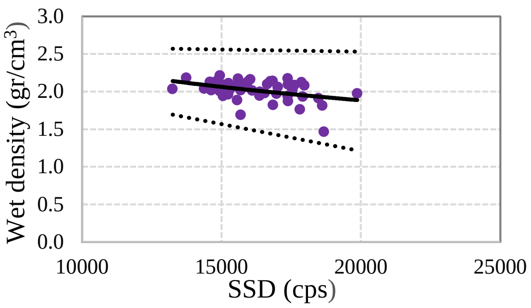

Fig.6 Plot of short-spaced density (SSD) and wet density

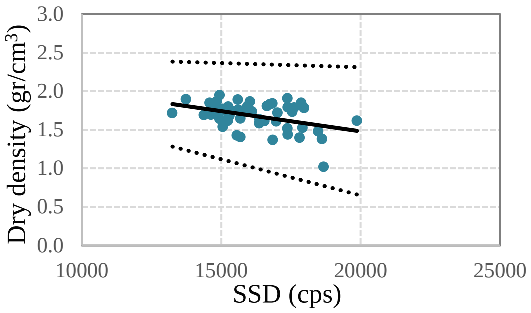

Fig.7 Plot of short-spaced density (SSD) and dry density

5. CONCLUSION

Warren equation cannot be applied to clastic sedimentary rock with low mechanical properties. The conversion result using the equation yields negative values, especially for short-spaced density (SSD) data. The model conversions of both short-spaced density (SSD) and long-spaced density (LSD) built from regression analysis also shows a poor result. The predictive ability is low, based on the shrunken R (R_S). Hence, density values in unit of cps obtained from both LSD and SSD logging cannot estimate well the actual density values in unit of g/cm^3 which are obtain from laboratory testing, for both wet and dry density. Determination of rock density is still recommended using laboratory tests of rock samples, instead of conversion model. The conversion model needs to be redefined regarding the population and the variables. A larger sample size may also help to get better result. In order to fulfill the local condition and to improve the accuracy of further analysis, it is required to modify the equation by adjusting the coefficients in the equation, so a more realistic and more suitable density model for the observed data will be obtained. As a result, it can minimize the errors produced in analyzing the type of rock.

Since each rock has its own characteristics, conversion model of cps to g/cm^3 must be built for each characteristic of rock. This shows that there is an open space for researcher to determine the conversion model with aim of utilizing geophysical data which are abundant for various purposes.

6. ACKNOWLEDGMENTS

The author would like to thank the management of PT Borneo Indobara for supporting this research.

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3624: Journal Revised paper

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3624: Journal Revised paper

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Best regards.

Prof. Dr. Zakaria Hossain

3624: Journal Revised paper

Paper ID number	3624
Revised Title	EMPIRICAL ANALYSIS OF DENSITY VALUE BASED ON LABORATORY TEST AND GEOPHYSICAL LOG
Full Name	Dr. Supandi Supandi
Corresponding Author's E-mail	supandi@sttnas.ac.id
All-authors E-mails Seperated by Comma	supandi@sttnas.ac.id
Revised Paper (Word)	[GEOMATE] Density Based on Lab Test vs Geophysical Log Rev_1.docx
Response to Reviewers	Response by Authors to Reviewer Supandi.docx
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