Influence of Physical Parameters to Time Domain Induced Polarization (TDIP) Response

Yatini[1*], D. Santoso[2], A. Laesanpura[2], and B. Sulistijo[3]

[1]*Geophysics Engineering, University of Pembangunan Nasional, UPN"Veteran" Yogyakarta SWK 104 North Ring Road Street Condong Catur 5528, Yogyakarta, Indonesia.*
[2]*Department of Geophysics Engineering, Faculty of Mining and Petroleum Engineering ITB, Bandung, Indonesia.*
[3]*Department of Mining Engineering, Faculty of Mining and Petroleum Engineering ITB, Bandung, Indonesia.*

*jeng_tin2004@yahoo.com

Abstract . The Induced Polarization (IP) method is one of geophysical method. This method is develop the resistivity method with additional measurement of ability of the ground to store electrical charge. The polarization electrode process are causal factor of IP response at metallic medium. The relationship between a metallic mineral content and TDIP response is tried to be quantitied.The TDIP response is influenced by porosity, grain size, clay and metallic mineral content. Measurement is performed in artificial samples that made of iron ore mixtured with quartz and cement. The samples are varied in iron ore content (0%-80%), grain size (65-300) micron and clay content (0%-25%). The greater total Fe content, the higher chargeability linearly M=0.08Fe+1.35. When the density becomes larger, chargeability rise exponentially M=0.347exp(0.852Dens). The presence of clay will enlarge the chargeability and minimize resistivity exponentially Rho=15.06exp(0.02C). Chargeability is lower and resistivity is higher for larger grain size. Increasing water saturation will reduce the value of resistivity Rho=600,7exp(-0.028W) for total Fe content of 28.3% and Rho = 191.4exp(-0.025W) to 21.2% total Fe.

Keywords: TDIP response, physical parameters, porosity and density.
PACS: 93.85.-q

INTRODUCTION

In the last 60 years Induced Polarization Geophysical method (IP) is widely used for metallic mineral exploration. The presence of metallic on sulfide minerals produces low resistivity and high polarisablelity. Time Domain Induced Polarization (TDIP) can provide informations of subsurface polarisablelity and resistivity. In its development, IP method is applied to solve environmental and engineering problems. IP method can be used to measure properties of conductivity and subsurface capacitance that can be done in the time and frequency domain.

IP response simply illustrates the degree of subsurface ability to store electrical current [1]. IP response on medium contained metallic mineral is large enough and affected by the metallic mineral's degree.

In general, the IP response is influenced by physical properties of medium. Chargeability becomes higher when the sulphide content is higher and it becomes lower when the grain size is larger, while the value of the resistivity does not fall continuously on the increase of the content of sulfide [2]. The presence of clay in the rock strongly influences the response of IP. Clay minerals interacting with groundwater can cause induced polarization and lower resistivity [3]. For 6.3% metallic sulphide content, the larger the grain size, the lower chargeability [4].

Grain size, porosity, clay mineral content, electrolyte composition and metallic mineral content are the dominant components affecting the IP response.

In this research, the effect of metallic mineral content to TDIP response is tried to be quantized. In samples containing metallic mineral, electrode polarization dominates the measurement results. The samples are made of a mixture of iron ore, quartz sand and cement. Their relationship is expected to be obtained by varying metallic mineral content and measuring IP response.

If the grain size, porosity, clay mineral content and the type of electrolyte in the artificial sample can be controlled, then IP response in the sample is dominated by metallic mineral content. IP response will change within the changes in the metallic mineral content.

METHODS

Sample Preparation

Samples are made of a mixture of iron ore, quartz sand and cement. Iron ore is used to determine the effect of metallic content, in this case total Fe or magnetite (Fe_3O_4). SiO2 (quartz) is a mineral resist against geological processes, so it almost always presents in each rock. Cement is used as an adhesive mixture. This artificial rock samples will be used as the target. Preparation of samples was done in accordance with the procedures of ASTM (American Society for Testing and Materials) quality standards.

The iron ore was obtained from iron ore mining on the southern coast of Yogyakarta. This sand has a total of 35% Fe content. Chemical test was conducted to determine levels of total Fe, Fe3O4 (magnetite) and other elements. Iron ore size ranges from 50 to 200 mesh (75 microns to 300 microns). Iron ore should be dried (in oven) with a temperature of 60°C. Quartz sand was derived from Tuban, East Java. The quartz sand was on Ngrayong formation. The advantages of quartz sand in these formations is it has a high quartz degree (98%).

Sieve analysis was done to obtain a sample with a relatively uniform grain size. Iron ore and quartz sand grain size were made to become same ie (-65 up to +100) # or (150-230) microns. In the Grain Size Classification table (Steve Mesh US Standart), this size is included in the category of Fine Sand (0.06 to 0.25) mm.

In the mixing processes, the same grain size of quartz sand and iron ore was taken to make the sample. The same grain size is expected to generate artificial samples of the same porosity as well.

The mixture is mould for obtaining the appropriate artificial samples. The moulding have the shape of cylindrical. Samples is made to TDIP response by measuring the resistivity and chargeability. In order to have a good mould, the mixture should be given water at a ratio of 3:1. This corresponds to Indonesian Industrial Standard (SII-0013-81), that now had been updated to SNI, which was adopted from ASTM C 150-80.

Induced Polarization Measurement

In simple terms, the IP response reflects the degree to which the subsurface is able to store electrical charge, analogous to a capacitor [1]. This polarization occurs at the interface between (1) a metal and a fluid (electrode polarization), and (2) a non-metal (e.g. silica or clay minerals) and a fluid (traditionally called membrane polarization).

Polarization results from a redistribution of ions along such interfaces following application of an electric current (Fig.1). Upon current termination, ions relax to the equilibrium condition. This diffusion-controlled relaxation is equivalent to a residual current flow (as observed during discharge of a capacitor) and is the source of the subsurface IP response. The IP method measures the magnitude of this polarization. In contrast, the resistivity method measures the magnitude of conduction provided by both electrolytic and surface conduction (enhanced in the presence of clay minerals). Electrode polarization generally produces a larger IP response than membrane polarization [5].

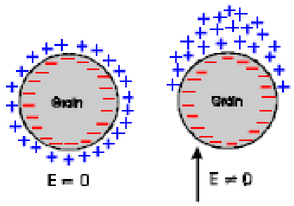

FIGURE 1. Equilibrium ion distribution and polarization following application of an electric field. Residual current flow occurs as ion relax to equilibrium following removal of electric field

In doing so, a low frequency current or direct current (DC) is injected at two current electrodes, while the potential difference is measured on the potential electrode. The square wave generated current electrodes and the signal received at the potential electrodes (Fig.2). When the current is disconnected, potential will immediately zero. However, in IP measurement, the potential will be zero for several time interval, this is called potential decay. Potential decay is due to the polarization in the subsurface medium.

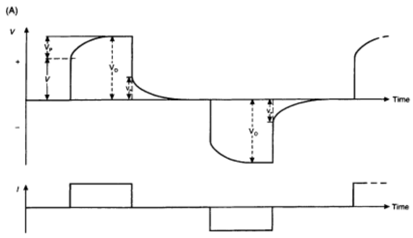

FIGURE 2. Time domain IP signal received showing measured parameters and current waveform : square- wave is generated low frequency.

At the time domain, there is most commond measurement is the chargeability defined as [6] :

$$M = \frac{1}{V_0}\int_{t_1}^{t_2} V_p(t)dt \qquad (1)$$

Where $V_p(t)$ is residual voltage integrates over time windoow defined between times t_1 and t_2 after termination of an applied current. V_o is the measured voltage at some time during application of the current. The unit of chargeability are quoted as milliVolt per Volt and is the most commonly used quantity in time domain IP measurement. When $V_p(t)$ and V_o, have the same units, the chargeability M is in millisecond

Experiment Outline

The effects of physical parameters on the TDIP response were done by measuring the TDIP response on artificial samples. TDIP response measurement was using IP meter Syscal series 568. The sample was placed on a holder connected to the transmitter and receiver (Fig. 3). Current electrodes was using a piece of copper which diameter corresponds to the sample size. Potential electrode was using porouspot [3,7].

Porouspot forms in which there is a copper pens are included in the $CuSO_4$ solution.

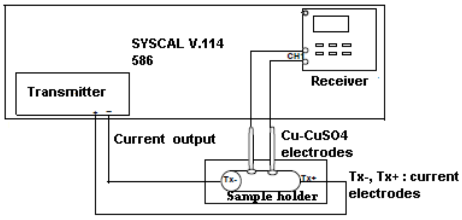

FIGURE 3. Equipment setting for TDIP measurement at tha sample.

THE RESULTS AND ANALYSIS

Porosity and density measurements were done by saturation [8]. For 2.5% iron ore content to 80%, the porosity of the samples is varied from 11.77% to 18.33% and density is varied from 1.78% to 2.58%, (Table 1). On the grain size of 75 to 300 microns, porosity is varied from 9.72% to 17.87% and the density is varied from 2.16 g/cc to 2.3 g/cc (Table 2). In samples with a variation of clay content, porosity ranges from 13.84% to 22.31% and the density ranges from 1.84 g/cc to 2.64 g/cc (Table 3).

ASTM procedures applied to sample preparation were expected to obtain the same results on all samples. In fact, the results of porosity were varied. This is due to the many factors that affect the porosity itself. The difference in pressure at the time of mixing and molding process is one of the cause.

Density is higher with increasing number of metallic minerals in the sample. The larger grain size, the greater porosity and the higher density. Greater content of clay would cause a smaller porosity and a higher density.

TABLE 1. Result of measurement at samples with varies in iron ore content

No	Sample	Iron ore	Fe total	Dens	n	Rho	M
	Code	content (%)	content	(gr/cc)	(%)	(Ohm-m)	(ms)
1	S13	80	28.27	2.58	14.94	43.10	4.23
2	S12	70	24.73	2.65	17.35	46.66	2.62
3	S11	60	21.20	2.38	15.68	10.40	1.65
4	S9	40	14.13	2.41	11.77	16.40	1.97
5	S8	30	10.60	2.04	15.56	12.96	1.6
6	S7	25	8.83	2.10	17.11	11.09	1.55
7	S5	15	5.30	2.02	16.86	21.28	1.4
8	S4	10	3.53	1.83	18.33	14.57	1.49
9	S3	5	1.77	1.80	14.19	19.74	1.4
10	S2	2.5	0.88	1.73	15.76	11.79	1.24

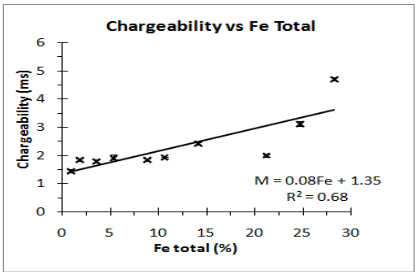

FIGURE 4. Chargeability vs Fe total. Linear correlation coefficient R^2 and error bars are shown.

TIDP responses that are chargeability and resisitivity depend on the number of metallic mineral content with linear equation M=0.08Fe+1.35 with R^2=0.68. The larger total Fe content, the resistivity drops into 21.20% Fe content, but rises for the larger degree of Fe content (Fig. 4). The higher density, chargeability also grows exponentially with the equation M=0.347exp(0.852Dens) and the value of R^2 =0.70, where M is chargeability and Dens is the density (Fig. 5).

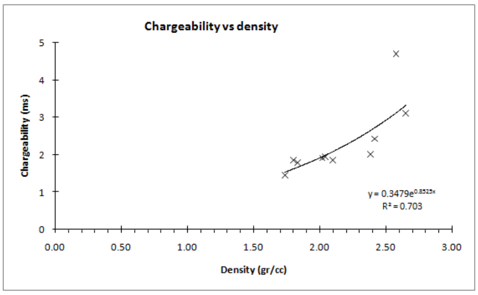

FIGURE 5. Chargeability vs density. Exsponential correlation coefficient R^2 and error bars are shown.

In the medium containing metallic minerals, chargeability is proportional to the area of cross section. The more metallic minerals, the bigger cross-sectional area and the higher TDIP response's chargeability. These results are the same with Mansoor[8]. Chargeability is relatively lower and resistivity is higher for the larger grain size. These results are consistent with the Pelton [4].

TABLE 2. Result of measurement at samples with varies in grainsize.

No	Sample	Grainsize	Grainsize	Dens	n	Rho	M
	Code	(mesh)	(micron)	(gr/cc)	(%)	(Ohm-m)	(ms)
1	S9-1	(+50)	>300	2.30	9.72	24.06	1.5
2	S9-2	(-50 sd +65)	230-300	2.28	12.71	25.10	1.54
3	S9	(-65 sd +100)	150-230	2.41	12.30	16.40	1.97
4	S9-3	(-100 sd + 150)	100-150	2.28	15.70	23.64	1.62
5	S9-5	(+200)	<75	2.16	17.87	15.63	1.43

Grain size will also affect the TDIP response. The larger grain size and porosity causes increasing density. Chargeability is lower and resistivity is higher for the larger grain size.

TABLE 3. Result of measurement at samples with varies in clay content.

No	Sample	Clay	Dens	n	Rho	M
	Code	content (%)	(gr/cc)	(%)	(Ohm m)	(ms)
1	S9	0	16.40	1.97	2.53	1.77
2	S9-b	2.5	11.06	1.65	2.25	1.45
3	S9-a	4.9	48.58	2.28	2.98	2.04
4	S9-c	7.5	13.53	1.70	2.25	1.5
5	S9-d	10	24.80	2.13	2.83	1.93
6	S9-e	15	32.46	2.66	3.47	2.36
7	S9-f	20	32.49	2.15	2.85	1.9
8	S9-g	25	10.43	1.70	2.29	1.5

Clay content in the medium containing the metallic also affects TDIP response. The larger clay content, the higher chargeability and the lower resistivity exponentially Rho=15.06exp(0.02C) and R^2=0,74.

The presence of clay leds to larger charge in the medium, so that the chargeability enlarges and the resistivity shrinks.

In the sample containing 80% iron ore, showed that the greater water content or water saturation causes increasing resistivity exponentially with equation Rho = 600.7exp (-0.028W) and R^2 = 0.92 (Fig. 6). In total Fe content of 28.3% and porosity of 13.4%, chargeability achieved maximum value for the saturation of 30% approximately (Fig. 7).

At iron ore degree of 60%, the equation is Rho = 191.4exp (-0.025W) and R^2= 0.89. In total Fe content of 21.2% and porosity of 15.7%, chargeability achieved maximum value at 55% saturation.

Saturation in the rock said to be 100% if all the pore spaces in the rock filled with water. The greater porosity, the saturation level values can be higher as well.

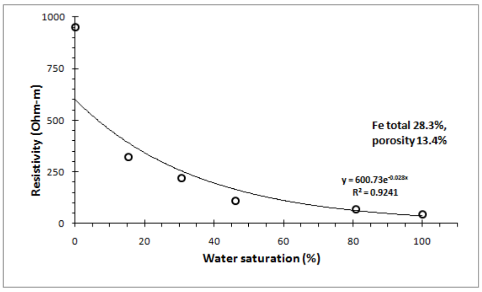

FIGURE 6. Chargeability vs density. Exsponential correlation coefficient R^2 is shown

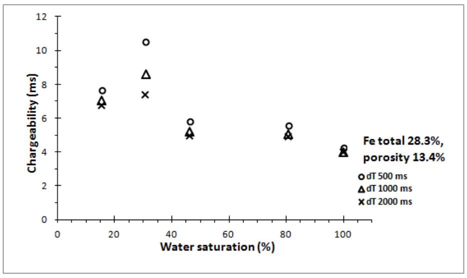

FIGURE 7. Chargeability vs water saturation at S-13 with 28.3% total Fe. Exsponential correlation coefficient R^2 and error bars are shown

CONCLUSION

From the research, the influences of physical parameters toward TDIP response on the artificial sample can be concluded:

- The greater the total Fe content, the higher chargeability, expressed by the equation M=0.08Fe+1.35. Greater density also increasing chargeability exponentially M=0.347exp (0.852Dens).
- The presence of clay will enlarge chargeability and minimize resistivity exponentially Rho=15.06exp(0.02C).
- Chargeability is lower and resistivity is higher for larger grain size.
- Higher water saturation will reduce the value of resistivity Rho=600.7 exp (-0.028W) for total Fe content of 28.3% and Rho=191.4 exp(-0.025W) for total Fe content of 21.2%.

ACKNOWLEDGMENTS

The study is financially support by Doctoral Hibah Research from `DIKTI. We thanks The Ministry of Education and Culture of Republic of Indonesia for doctoral scholarship. We thanks to Sisca and Wawan who helped with the laboratory measurements included in this study and Dyah Probowati and Sudaryanto chairmans Coal and Ore Processing Laboratory, UPN "Veteran" Yogyakarta who has provided space in the laboratories.

REFERENCES

1. J.S. Sumner, *Principles of induced polarization for geophysical exploration*, Amsterdam: Elsevier Scientific, 1978, p.277
2. W.J. Scott and G.F. West, *Geophysics* **34**, 87-100 (1969).
3. H. Vanhala and H. Soininen, *Geophysical-Prospecting* **43**, 454-472 (1995).
4. W.H. Pelton, S.H. Ward, P.G. Hallof, W.R. Sill, P.H. Nelson, *Geophysics* **43**, 588-609 (1978).
5. L.D. Slater, D. Lesmes and S.K. Sanberg, Proceeding of the Symposium on the Application of Geophysics to Engineeing and Enviromental Problems, 2000, pp. 935-944.
6. S.H. Ward, *Soc Explor Geophys* **4**,147-190(1990).
7. J. Kiberu, "IP and Resistivity measurement on suite af near surface soil samples and their empirical relstionship to selected measured engineering parameters", Master. Thesis, ITC, 2002.
8. J.A. Franklin and U.W. Vogler, *Int. J. Rock Mech. Min. Sci. and Geomech* **16** : 141–156 (1979).