Physical Modeling Studies of the Time Domain Induced Polarization (TDIP) Response, Case : Homogeneous Isotropic Medium

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Abstract*— Method of Induced Polarization (IP), including part of the geoelectric method, which utilizes the electrical and polarisabelity properties of the medium. Parameter the time domain induced polarization response, depends on the medium below the surface. TDIP response parameters such as resistivity and chargeability. Both of these parameters can be used to determine the mineral content of metal at subsurface. Relationship IP response parameter and metal mineral content is not known with certainty. Though the subsurface information of the metal content is a very important target in the exploration using the IP method. Therefore it is necessary studies on the relationship of concentration of metallic minerals below the surface of the induced polarization response. In this research sought quatitative relationship between the concentration of metallic minerals beneath the surface against induced polarization response in the time domain. That is done by mathematical and physical modeling. Mathematical modeling will result in an IP response in the form of curves with a variety of connection parameters. While physical modeling will be generated from the IP response to various parameters of the target measurement. Quantitative relationship between IP responses and metal mineral content obtained by analysis of the response curves matching the IP results and the mathematical and physical modeling.

I. INTRODUCTION

The Induced Polarization (IP) including part of the Geoelectric methods, widely used to the exploration of base metal. One of the measured parameters can be used to distinguish the polarisablelity of the medium, which is indication of metal minerals. Metallic minerals which are the target of exploration using IP method is very important to know.

Induced polarization responses were measured on the surface of the earth caused by measurement techniques and subsurface conditions. The existence of metallic mineral deposits, the role of ground water or fluid type, porosity and geometry anomalies are affect on the response.

The relationship between the mineral content of metals in the subsurface medium and induced polarization response measured is not known with certainty. Some researchers are trying to explain how the effect on metallic minerals to the TDIP response. Most of them do rock samples. In fact, the results of measuring of rock samples will be very different from in situ. This is due to many things, among others, because the physical (temperature, humidity, fluid content, porosity, etc.) in the sample is very different from the in situ, of course the measured physical parameters are also different. Scott and West (1969) measure of rock samples, chargeability greater if the higher sulphide content and will smaller if the grain size is larger, while the value of the resistivity does not decrease continuously to the increase in sulphide content. Chargeability also proportional to the volume of pores in the soil containing iron minerals 0.25% to 1.63% (Mansoor and Slater, 2007). Slater et.al (2006) conducted measurements of IP on artificial samples consisting of a mixture of sand and iron. He obtain a linear relationship between the response TDIP and the pore surface area on the mixture of sand and iron, but not linear with respect to metal content.

Therefore, it is necessary to obtain relationships mineral deposits below the surface of the measured surface TDIP response. In this study, the relationship will be sought by modeling studies. This includes mathematical, laboratory-scale physical and inversion modeling. Mathematical modeling is intended responses of TDIP theoretically, by taking the ideal models with various parameters and calculate the response. Looking TDIP response is basically solve the Laplace equation, with the boundary to the model being simulated. The relationship between the response parameters used definition of Siegel and Wait. This modeling will produce theoretical TDIP response, in the form of curves with a variety of connection parameters.

While physical modeling is intended to obtain the results of measuring physical parameters TDIP response to subsurface conditions are known. Initially conducted physical modeling subsurface model and the ideal model to measure the IP response. Then by altering physical parameters and make the variation of the target metal mineral content on physical models and measuring its response TDIP, will yield a variety of parameters with a variety of metallic mineral content. It also made for different physical models. The quantitative relationship between the TDIP response and metals mineral content obtained by analysis of the response curves matching TDIP response results of mathematical and physical modeling.

The quantitation results of curves analysis methods will be tried applied to the field data. Data aquisition is done by field measurement tools and techniques similar to those performed on physical modeling. By applying the appropriate scaling factor, it is expected the results will be better. TDIP field data in the time domain is taken in mineralization areas (Yatini, et.al., 2012). By knowing quantitation relationship response and metallic mineral deposits, is expected to know the distribution and geometry of rocks with high metallic mineral deposits at subsurface

Research purposes

Getting a quantitative relationship between the metal and mineral content parameters induced polarization response in the time domain. Make physical models to study the behavior of the IP response anomalies caused by metallic mineral distribution. Obtain information on the results of groundwater TDIP response, which is used as a homogeneous isotropic medium approach

II. BASIC THEORETICAL

A. Basic Principles of Induced Polarization Method

Method of Induced Polarization or IP use electrical and polarisablelity properties of rocks as a base. Current is sent through the electrode current and voltage to be measured on the electrode potential. If the current is cut off abruptly, the voltage should also be immediately precious zero (Reynold, 1997). In fact the voltage gradually decreases exponentially, then for a certain time interval (a few seconds or minutes) will be zero voltage. This is because the return of conductive ions in the medium proceeds back to positions and the original state, as before electrified. The effect is called the induced polarization. Illustration of induced polarization phenomena can be described in Fig 1, direct current (DC) flows through a series of four electrodes and turned off suddenly, caught on the electrode potential potentially go straight to zero, but it down gently called potential decay.

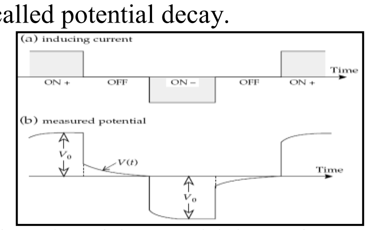

FIG. 1. (a) an illustration of the potential decay of current is turned off (b) effect of IP with respect to time decay on the injection current wave box (Telford, et. al.,1990).

The cause of the induced polarization effect is quite complex. Some researchers tried to explain the effect of induced polarization that occurs in rocks. In general there are two causes of polarization effects of the medium, the polarization of the membrane and electrode.

B. Measurement of Induced Polarization Effects

In general, there are two Induced Polarization (IP) measurements effect, in the frequency and time domain.

1. The frequency domain. Done by injecting a low-frequency current (e.g. 0.1 Hz) and high frequency (10Hz), and then measure the potential. In the frequency domain, polarization induced effect noted by PFE (Percent Frequency Effect).

$$PFE = \frac{\rho_l - \rho_h}{\rho_h} 100 \qquad (1)$$

   Where ρ_l dan ρ_h apparent resistivity in low and high frequency. Marshal and Madden (1959) introduce metal factor quantity (MF) with units of mhos/m.

$$MF = \frac{2\pi * 10^3 PFE}{\rho_l} \qquad (2)$$

2. The time domain. There are two ways i.e. compare the residual potential (Vs) is left at time (t) after the termination of current and potential for measurable current flows (Vt). The value of the potential difference the absence of current that pass are recorded as secondary potential difference in function of time (Vp). as shown in Fig. (3). Unit of chargeability (M) is (mV/V).

$$M = \frac{V_s}{V_p} \qquad (3)$$

   The second way the integration potential decay on a potential difference before the current is turned off, in a specified time interval. In this way chargeability (M) has units of (msec) so that the chargeability can be in the form of the equation.

$$M = \frac{1}{V_P} \int_{t_1}^{t_2} V(t)dt = \frac{A}{V_P} \qquad (4)$$

   Where A is the area of the diarsir and VP are the primary voltage. Measurement of the parameters of the relationship of frequency and time:

$$FE = \frac{M}{(1+M)} = M \text{ untuk } M<<1 \qquad (5)$$

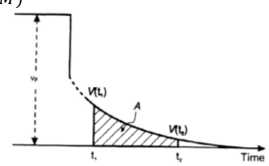

FIG. 2. Potential decay to calculate the IP parameters (Reynolds, 1997).

C. The electrode configurations

TDIP data retrieval done by injecting current through the C_1C_2 and measure P_1P_2 potential (Fig. 3). Current is sent then be stopped, the potential should be zero, but it will go to zero for a few seconds or minutes. By measuring the decay time, then the chargeability value will be at each electrode position.

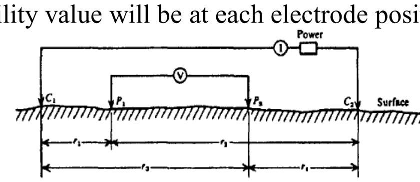

FIG. 3. The current electrode (C_1C_2) dan potential (P_1P_2) on the surface of a homogeneous isotrop medium with resistivity ρ (Telford, 1990).

In principle, the same electrode array as geoelectric method, for mapping used Wenner and dipole-dipole and Schlumberger soundings used (Fig 4)

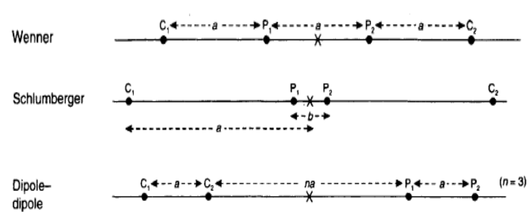

FIG. 4. Electrode configuration of Wenner, Schlumberger and Dipole-dipole (Reynold, 1997).

D. The relation of IP variables

Polarisabelity of subsurface can be obtained by measurements using four-electrode configuration. If the target is more or less polarisable than rock (medium) around it, then polarisabelity outcome measure (apparent) will be smaller or larger than the true polarisablelity target. This effect is called 'dilution'.

Defined apparent chargeability (m_a) is the ratio beetwen the change in apparent resistivity increase and the apparent resistivity when it does't occur the polarization (Apparao, 1997, Wait, 1988)

$$m_a = \frac{\partial \rho_a}{\rho_a}$$

If there are two medium below the surface is

$$m_1 = \frac{\partial \rho_1}{\rho_1} \quad \text{and} \quad m_2 = \frac{\partial \rho_2}{\rho_2}$$

Surface resistivity measured all apply:

$$\rho_a = \rho_1 \frac{\partial \rho_a}{\partial \rho_1} + \rho_2 \frac{\partial \rho_a}{\partial \rho_2}$$

$$\frac{\partial log\rho_a}{\partial log\rho_1} = 1 - \frac{\partial log\rho_a}{\partial log\rho_2} \quad (6)$$

$$m_a = m_1 \frac{\partial log\rho_a}{\partial log\rho_1} + m_2 \frac{\partial log\rho_a}{\partial log\rho_2} \quad (7)$$

Subtitution (6) to (7) :

$$\frac{m_a - m_1}{m_2 - m_1} = \frac{\partial log\rho_a}{\partial log\rho_2} \quad (8)$$

For m_1=0, meaning that one of the medium (host medium) below the surface is a non polarisable, then

$$m_a = m_2 \frac{\partial log\rho_a}{\partial log\rho_2} \quad (9)$$

$\frac{\partial log\rho_a}{\partial log\rho_2}$ dilution factor.

From equation (8) can be generally understood that the polarizing effect of the anomalous objects depends on the contrast polarization and resistivity change effects for the overall apparent resistivity.

For subsurface consisting of many targets, the magnitude of apparent chargeability formulated (Siegel, 1959) as follows:

$$m_a = \sum_i m_i \rho_i \frac{\partial \rho_a}{\partial \rho_i} / \rho_a$$

$$m_a = m_1 \frac{\partial log\rho_a}{\partial log\rho_1} + m_2 \frac{\partial log\rho_a}{\partial log\rho_2} + \cdots + m_n \frac{\partial log\rho_a}{\partial log\rho_n} \quad (10)$$

III. RESEARCH METHODOLOGY

A. Mathematical modeling

Development of mathematical formulas on the phenomenon of polarization based on the potential field caused by the distribution volume element dipole.

Homogeneous isotropic medium current-carrying density J, apply Ohm's law as follows :

$$J = \sigma E \quad (11)$$

Where J is the current density, the current through broad unity. E is the electric field and conductivity σ (S / m)

The electric field is the gradient of a scalar potential

$$E = -\nabla V \quad (12)$$

Will be obtained: $J = -\sigma \nabla V$

$\nabla . J = 0$, so $\nabla . (\sigma \nabla V) = 0$ and $\nabla \sigma . \nabla V + \sigma \nabla^2 V = 0$

From the equation is obtained Laplace equation, as follows

$$\nabla^2 V = 0 \quad (13)$$

Potential on the surface caused by objects on subsurface, is essentially a solving of Laplace equation. So to find out TDIP responses i.e. resisitivity and chargeability by completing the Laplace equation. The following are the model homogeneous and isotropic and solid sphere.

Homogeneous isotropic medium.

Ideal model begins with the halfspace homogeneous isotropic medium. Response TDIP form and chargeability resistivity parameter. In homogeneous isotropic medium, no chargeability parameters (m = 0). The relationship between the measured resistivity and potential surface depends on the electrode array or electrode configuration. The potential difference measured at surface with four electrode (Fig 3) are:

$$\Delta V = \frac{I\rho}{2\pi} \left\{ \left(\frac{1}{r_1} - \frac{1}{r_2} \right) - \left(\frac{1}{r_3} - \frac{1}{r_4} \right) \right\}. \quad (14)$$

r_1= C_1P_1, r_2= P_1C_2, r_3= C_1P_2 dan r_4= P_2C_2.

Wenner configuration (Fig. 4) r_1=r_4=a and r_2=r_3=$2a$, a is spacing.

Relation between resistivity and the potenstial is :

$$\rho_a = 2\pi a \frac{\Delta V}{I} \quad (15)$$

Dipole-dipole configuration (Fig. 4.), resistivity :

$$\rho_a = \pi a n (n+1)(n+2) \frac{\Delta V}{I} \quad (16)$$

Where n = 1,2, ..., 8 and a is the electrode spacing. For homogeneous isotropic medium, apparent resistivity value equal true resistivity.

Solid sphere model.

On models with a solid sphere of radius a and depth z from the surface, the resistivity is:

$$\frac{\rho_a}{\rho_1} = -2 \left(\frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} \right) a^3 \frac{(2x^2 - z^2)}{(x^2 + z^2)^{5/2}} \quad (17)$$

Where z is the depth of the center of the sphere, if z = 2a, then a comparison ρa and ρ1 only 12%. If a / z = 2 or z = 0.5A means half the sphere was exposed on the surface and the other half is under the surface. Chargeability and resistivity of the relationship, it is obtained apparent chargeability that measured at surface.

Parameter chargeability on the sphere at subsurface that is surrounded by a medium non polarisable or host in the form of water (m_1 =0), then the measured apparent chargeability at surface becomes

$$\frac{m_a}{m_2} = \frac{\partial log\,\rho_a}{\partial log\,\rho_2} = \frac{\partial \rho_a}{\partial \rho_2} = 4a^3 \left(\frac{\rho_1}{(\rho_1 + \rho_2)^2} \right) \frac{(2x^2 - z^2)}{(x^2 + z^2)^{5/2}} \quad (18)$$

Where m_2 and ρ_2 are chargeability and true resistivity of the solid sphere. If apparent chargeability at surface is smaller than the true chargeability of the target, then it is called dilution effect (Apparao, 1997)

B. Physical modeling.

Physical modeling in this study is one step to obtain the relationship between the mineral content of the metal with the parameters in the time domain induced polarization. Besides, it will also to obtain influence the measurement technique these parameters.

To determine the effect of the metal content of the IP response, research by creating physical models with Dipole-dipole and Wenner configuration, on the sandbox (200cmx100cmx70cm) (Fig. 5a). TDIP responses were measured on the surface IP-meter Syscal the max 1200 mA output current.

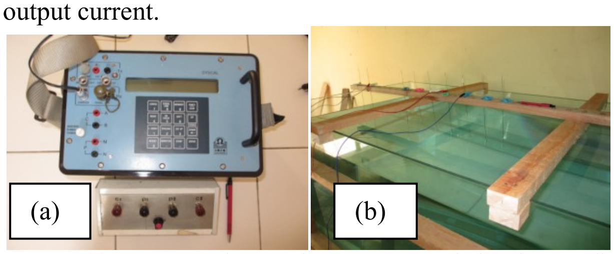

FIG. 5. (a) IP Meter Iris Syscal Instruments and (b) glass sandbox size (200cmx100cmx70cm) were used for physical modeling.

IV. CASE: HOMOGENEOUS ISOTROPIC MEDIUM

The cause of the induced polarization in the medium is influenced by many things such as the role of the fluid, and the relationship between grain size, the presence and condition of conductive metallic mineral or minerals and others. In addition to the geometry and position below the surface, and the use of measurement techniques electroda configuration also influences. Physical modeling of induced polarization response, serves to control parameters such as grain size, the content of fluid, electrolyte concentration, metal mineral content. In this case the target of the research is the extent to which the parameters of the mineral content of metals in various mediums affect the results of measuring the response in the time domain induced polarization.

Mathematical modeling to calculate the response of the ideal forms with a variety of parameters, intended to produce a theoretical response curve TDIP. TDIP theoretical response curve has patterns, shapes and profiles that depend on parameter variations and relationships between parameters. Of course, for the same condition with physical models, the response curve and the results of theoretical calculations TDIP responses measuring results of physical models will be the same.

For example in a homogeneous isotropic medium theoretically, produce a response in the form resisitivity TDIP only. In the physical model of the host medium is water, will only generate response TDIP resistivity, because the water has no chargeability value. The resistivity results count and measure, should be the same.

By comparing responses count results of mathematical models and physical measurement results from different ideal models, in possible to make a mistake or error as small as possible. Making ideal models performed in this study, correlated with the subsurface geology

If the error is small, meaning that the physical model is created according to the results of mathematical count of the IP response. This means, the quantitative relationship between the TDIP response to metal mineral deposits with a variety of parameters has been obtained

In the case of a homogeneous isotropic medium, the measurement of the response in the time domain induced polarization conducted on sandbox (200cmx100cmx70cm). Groundwater used as a homogeneous isotropic medium approach (Apparao, 1997). To know the characteristics of this medium, the measured response in the time domain induced polarization (TDIP). Use stainlesstel as electrode current and potential electrode porouspot as is right, because it is non polarisable eletrode porouspot so that the small potential (in mV order) can be measured with good. Measuring response TDIP on homogeneous isotropic medium, using dipole-dipole configuration (spaced 10 cm) and Wenner.

The early stage of the response measurements in the time domain induced polarization (TDIP), conducted in a homogeneous isotropic medium. Water is used to approximate a homogeneous isotropic medium, because of the nature of water that can flow in all directions with the same current. Water is used as the host medium, the physical modeling work (Majumdar 1984, Apparao, 1997, Sarma, 2009). The water can also be measured directly, so the value of the resistivity measuring value can be compared with the results measured using electrode configurations.

Measurements performed on the medium response TDIP water with a few different configurations, i.e. Wenner, Dipole-dipole and Schlumberger. Wenner configuration with spaced 5, 10, 15, 20, 25, 30, 35 and 40 cm. While the measurement of Dipole-dipole configuration with spaced 5, 10, 15 and 20 cm.

The use of electrode potential, will largely determine the quality of the result in physical modeling. Therefore, several electrodes are used to measure potential homogeneous isotropic medium (water) in the considerable time is 30 minutes with an interval of 30 seconds. Electrodes are stainlesstel, copper, and iron mixed Zeng, AgCl and porouspot. The results showed that the electrode potential porouspot produces a very small (close to zero) and very stable, so for further data collection is used porouspot.

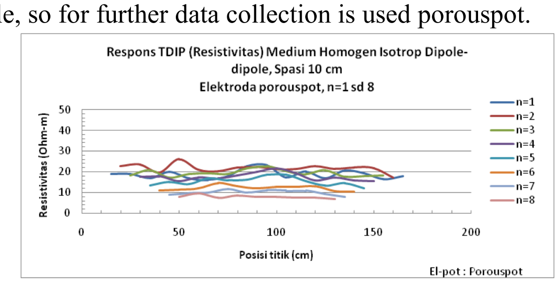

FIG. 6. TDIP for resistivity response n = 1 to 8 with porouspot electrodes.

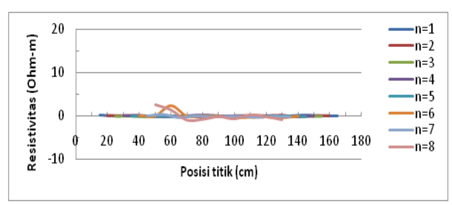

FIG. 7. The results of measuring the response TDIP (chargeability) in homogeneous isotropic medium (water) Dipole-dipole configuration, use porouspot electrodes, spaced 10 cm, for n = 1 to 8.

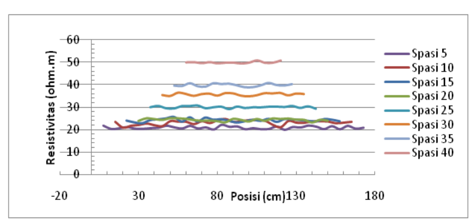

FIG. 8. The results of measuring the response TDIP (resistivity) in a homogeneous isotropic medium (water) Wenner configuration, spaced 5 to 40 cm, porouspot electrode.

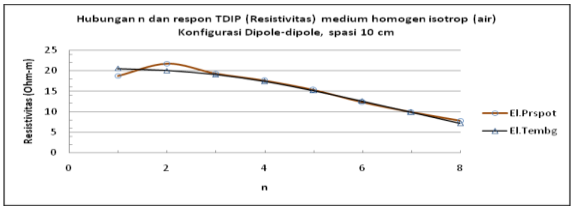

FIG. 9. Relationship TDIP (resistivity) response obtained and n, in the medium of groundwater, Dipole-dipole configuration, spaced 10 cm.

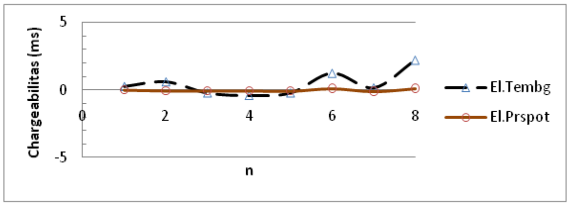

FIG. 10. Relationship TDIP response (chargeability) obtained and n, the homogeneous isotropic medium (groundwater), Dipole-dipole configuration, spaced 10 cm.

Measuring response TDIP on homogeneous isotropic medium (groundwater) produces the TDIP response parameter i.e. resistivity and chargeability. TDIP response with Dipole-dipole configuration is getting smaller for the greater value of n (Fig 9), both with porouspot and copper electrodes. The average resistivity values produced the same at 16.1 Ohm-m (for n = 1 to 8), and 19.3 Ohm-m (for n = 1 to 4). But with a Wenner electrode resistivity porouspot yield on average higher at 28.4 Ohm-m (for all n) and 9.22 Ohm-m for n = 1 to 4 (Fig 8).

In the geoelectric method, current and potential electrode separation greatly affects the depth penetration. In the configuration Wenner and Dipole-dipole, the lower the signal sensitivity for the higher value of n. Use n = 1 to 4 good sensitivity, while for n> 5 smaller sensitivity so resolution is low. Wenner and Dipole-dipole near the surface good and sensitive to distinguish the lateral variation (Reynolds, 1997, Apparao, 1997, Loke, 2000, Milsom, 2003).

Groundwater resistivity measurement results Dipole-dipole is 3.19 Ohm-m (Fig. 6), while the Wenner produced 28.4 Ohm-m (Fig. 8). Both of these results are in the range of groundwater resistivity values of 10 to 100 Ohm-m (Telford, et al, 1990). This result is not too much different from the measurement of groundwater samples were 30.0 Ohm-m.

For chargeability, the resulting value of the dipole-dipole electrode porospot is very small at 0.015 ms and copper electrodes at 0.36 ms (Fig. 10). It is proved that the use of porouspot electrode is better. To use copper electrodes, chargeability have higher value because due to the polarization surrounding the electrode potential. By looking chargeability values are close to zero, then the groundwater can be used to approach the concept of homogeneous isotropic medium. Since the medium is homogeneous isotropic non polarisable (chargeability is 0).

V. CONCLUSION

In TDIP physical modeling, groundwater can be used to approach a homogeneous isotropic medium, because the chargeability value 0.015 ms (close to 0). Using porouspot electrode as the electrode potential is very precise. Results TDIP response in groundwater with Dipole-dipole configuration was 19.3 Ohm-m, while the Wenner 28.4 Ohm-m. These results are close to the value of the groundwater sample measurement 30.0 Ohm-m

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