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# Design Analysis of Impressed Current Cathodic Protection for Fuel Distribution Pipeline System at Eastern Fleet Command Naval Base

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***Abstract:***
*Fuel is main requirement of KRI (Indonesian Warship) in activities of basic training, warfare alert and operation at sea. To pock of fuel demand from KRI at Eastern Fleet Command Base, it needs a new pipeline of fuel distribution system. The pipeline system used for maximum lifetime must be protected from corrosion. Basically, there are five methods of corrosion control such as change to a more suitable material, modification to the environment, use of protective coating, design modification to the system or component, and the application of cathodic or anodic protection. Cathodic protection for pipeline available in two kinds, namely Sacrifice Anode and Impressed Current Cathodic Protection (ICCP). This paper makes analysis from design of Impressed Current Cathodic Protection and total current requirement in the method. This paper showed both experimental from speciment test and theoritical calculation. The result showed that design of Impressed Current Cathodic Protection on fuel distribution system requires voltage 33,759 V(DC), protection current 6,6035 A(DC) by theoritical calculation and 6,544 A(DC) from pipeline specimen test, with 0,25 mpy for corrosion rate. Tranformer Rectifier design needs requirements 45 V with 10 A for current. This research result can be made as literature and standardization for Indonesia Navy in designing the Impressed Current Cathodic Protection for fuel distribution pipeline system.*

***Keywords:*** *Fuel distribution system, corrosion, Cathodic protection, ICCP, Rectifier*

## 1. Introduction

The main requirement for KRI (Indonesian Warship) in activities of basic training, warfare alert and operation at sea is fulfilled by demand. Fuel is used for main engine and electricity.

With the condition background what are demanded from KRI, it is urgent to make design of fuel pipeline distribution system in Eastern Fleet Naval Base (Koarmatim) for supporting warfare alert, basic training and operation activities at sea. The pipeline system has negative effect from corrosion. Corrosion is the destructive attack of a material by reaction with its environment (Roberge, 1999).Because of that, the pipeline system needs protection from corrosion that can applied underground.

In today's regulated environment, a method to potect corrosion of all new hazardous pipelines (carrying oil, gas, or other potentially dangerous substances) is required by federal regulation to use an effective coating and cathodic protection (Parker, 1999). Cathodic Protection (CP) is a proven method of controlling corrosion in reinforced concrete through the application of a small Direct Current (DC) (Nguyen, Lambert, Mangat, O'Flaherty, & Jones, 2012). There are two types of applying cathodic protection system, namely Sacrificial Anode Cathodic Protection (SACP) and Impressed Current Cathodic Protection (ICCP) (Al-Himdani, Mahdi, & Khuder, 2005).

Impressed Current Cathodic Protection (ICCP) is a method to prevent corrosion by allowing an appropriate DC to flow continuosly through metal bodies in contact with wet soil or a corrosive aqueous solution. It employs a direct current generator (rectifier) that has the pipe connected to the negative terminal of the rectifier, whereas the selected anode is connected to its positive terminal, thereby making the current flow from the selected anode to the onshore pipe forcibly and thus preventing corrosion currents in the pipeline. This is also called forced current method (Choi, Kim, & Oh, 2016).

This paper has many literature to support the research about it, for example paper with the tittle Shipboard Impressed Current Cathodic Protection System (ICCP) Analysis (Hogan, Lucas, & Wimmer, 2005). Effectiveness of Impressed Current Cathodic Protection System in Concrete Following Current Interruption (Bhuiyan, 2015). Modeling and Control of Impressed Current Cathodic Protection (ICCP) System (Hashim, Mohammed, & Hamadi, 2014). Assessing the long term benefits of Impressed Current Cathodic

Protection (Christodoulou, Glass, Webb, Austin, & Goodier, 2010). ICCP cathodic protection of tanks with photovoltaic power supply (Janowski & Wantuch, 2016). Efficiency of Corrosion Inhibitors on Cathodic Protection System (Briggs & Eseonu, 2014). The Impressed Current Cathodic Protection System (Kakuba, 2005). System Identification Modelling and IMC Based PID Control of Impressed Current Cathodic Protection System (Balla, et al., 2013). Identification and Control of Impressed Current Cathodic Protection System (Sada, Ali, & Ali, 2016) . The application of impressed current cathodic protection to historic listed reinforced concrete and steel framed structures (Broomfield, 2004).

This paper presents design of protection system and total current needed in the ICCP method. It has been an effort to apply design of corrosion prevented ICCP method for fuel pipeline distribution system in Koarmatim, and to analyze corrosion rate from pipeline specimen test. The inscriptive benefit from this paper is a literature for Indonesia Navy about the design of fuel distribution pipeline system in Koarmatim. It can be made as standarization for design of ICCP at fueled pipeline in Koarmatim. Such courses if it gives description by the student helps about their study program.

This paper is organized as follows. Section 2 reviews the basic consepts of corrosion control. Section 3 gives result of research. Section 4 describes the analysis of Impressed Current Cathodic Protection System in fuel distribution pipeline. Finally, in section 5 presents this paper conclusion.

## 2. Research Methodology

### *2.1. Corrosion*

Corrosion is defined as the destruction or deterioration of material because of reaction with its environment. Some insist that the definition should be restricted to metals, but often the corrosion, engineers must consider both metals and nonmetals for solution of given problem (Fontana, 1987). Corrosion is the damage to metal caused by reaction with environment. (Bradford, 2001). Corrosion is the degradation of material through environmental interaction (Peabody, 2001).

The corrosion process involves the removal of electrons (oxidation) of the metal and the consumption of those electrons by some other reduction reaction, such as oxygen or water reduction respectively(Peabody, 2001).

$$Fe \rightarrow Fe^{2+} + 2^{e-} \tag{1}$$

$$O_2 \rightarrow 2H_2O^{+} + 4^{e-} \tag{2}$$

$$2Fe + O_2 + 2H_2O \rightarrow 2Fe^{2+} 4OH^{-} \tag{3}$$

The oxidation reaction is commonly called the anodic reaction (1) and the reduction reaction (2) is called the cathodic reaction. Both electrochemical reactions are necessary for corrosion to occur. The oxidation reaction (3) causes the actual metal loss but the reduction reaction must be present to consume the electrons liberated by the oxidation reaction, maintaining charge neutrality. Otherwise, a large negative charge would rapidly develop between the metal and the electrolyte and the corrosion process would cease. The oxidation and reduction reactions are sometimes referred to as half-cell reactions and can occur locally (at the same site on the metal) or can be physically separated. When the electrochemical reactions are physically separated, the process is referred to as a differential corrosion cell (Peabody, 2001).

There are four necessary components of a differential corrosion cell (Bradford, 2001)

1) The anode, which is the metal that is corroding.
2) The cathode, which is a metal or other electronic conductor whose surface provides sites for the environment to react.
3) The electrolyte, (the aqueous environment), in contact with both the anode and the cathode to provide a path for ionic conduction.
4) The electrical connection between the anode and the cathode to allow electrons to flow between them.

### *2.2. Corrosion Rate*

Corrosion rate is the amount of corrosion occurring per time unit (for example, mass change per area unit per time unit, penetration per time unit). The humidity, temperature fluctuations, wide variations in rainfall, wind, and pollutants prevent classification scheme to indication of corrosion rates (Roberge, 1999). One of them can use electrical method. It calculates with equation (NACE, 2002).

$$Corrosion\ rate = K\,\frac{Icorr\ x\ E}{D} \tag{4}$$

| Relative Corrosin | Approximate Metric Equivalent | | | | |
|---|---|---|---|---|---|
| Resistance | mpy | mm/yr | µm/yr | nm/yr | pm/s |
| Outstanding | <1 | < 0,02 | < 25 | < 2 | < 1 |
| Excellent | 1 - 5 | 0,02 - 0,1 | 25 - 100 | 2 - 10 | 1 - 5 |
| Good | 5 -20 | 0,1 - 0,5 | 100 - 500 | 10 - 50 | 5 - 20 |
| Fair | 20 - 50 | 0,5 - 1 | 500 - 1000 | 50 - 150 | 20 - 50 |
| Poor | 50 - 200 | 1 - 5 | 1000 - 5000 | 150 - 500 | 50 - 200 |

*Table 1: Value of Corrosion Rate (Fontana, 1987)*

### *2.3. Corrosion Control Method*

Corrosion prevention can take a number of forms depending on the circumstances of the metal being corroded. There are basically five methods of corrosion control: change to a more suitable material, modification to the environment, use of protective coating, design modification to the system or component, and the application of cathodic or anodic protection (Roberge, 1999).

The basic principle of cathodic protection (CP) is a simple one. Through the application of cathodic current onto a protected structure, anodic dissolution is minimized. Cathodic protection is often applied to coated structures, with the coating providing the primary form of corrosion protection. The CP current requirements tend to be excessive for uncoated systems. Its installations include buried tanks, marine structures such as offshore platforms, and reinforcing steel in concrete (Roberge, 1999). Its result can be achieved in two distincly different ways, Sacrificial Anode and Impressed Current (Bradford, 2001).

### *2.4. Impressed Current Cathodic Protection*

Impressed Current Cathodic Protection (ICCP) is applied by means of an external power current source (Roberge, 1999). It uses a power to move the current from a very noble anode material to protect the structures (Orazem, 2014). Its current is impressed on the structure by means of a power supply, referred to as a rectifier, and anode buried in the ground (Peabody, 2001).

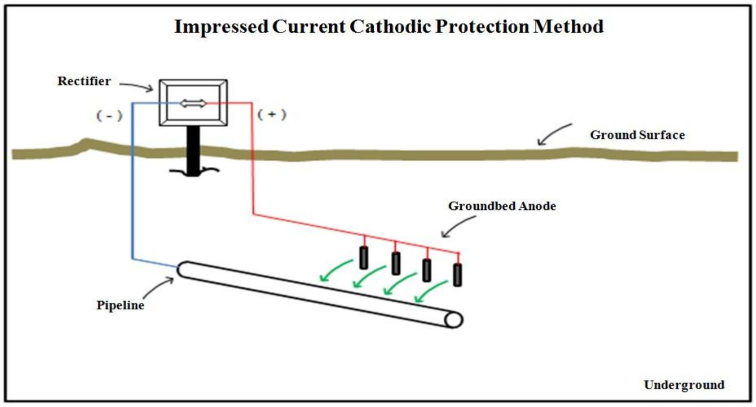


*Figure 1: ICCP Method*

The external current supply is usually derived from a Transformer Rectifier (TR), in which the AC power supply is transformed (down) and rectified to give a DC output. Other power sources include fuel or gas driven generators, thermoelectric generators and solar and wind generators. Important application areas of impressed current system includes pipelines and other buried structures, marines structures, and reinforcing steel embbeded in concrete (Roberge, 1999).

Some advantages of ICCP are as follows:

a. High current and power output range.
b. Ability to adjust the protection levels.
c. Large areas of protection.
d. Low number of anodes, even in high-resistivity environment.
e. Even protecting poorly coated structures.

These limitations that have been identified for ICCP system :

a. Relatively high risk of causing interference effects.
b. Lower reliability and higher maintenance requirements.
c. External power has to be supplied.
d. Running cost of external power consumption.

### *2.5. Method of Research*

This paper shows both experimental from speciment test and studied in detail numerical calculation design of ICCP. The numerical result is compared with experimental results showing criteria for design of ICCP in fuel pipeline distribution system. The first phase is identification of the problem, library studies, and the planning of cathodic protection system.

#### 2.5.1. Numerical Calculation Design

Numerical calculation design is conducted prior to detailed design of ICCP to achieve value of the system requirements. Its reports describe the investigations made and measurements taken, and make recommendations the result of building design. It has many steps to design(NACE, 2002):

a. Soil resistivity.
b. Surfaces range of pipeline system has protected.
c. Protecting current requirement.
d. Pipeline resistance.
e. Coating conductance.
f. Attenuation constant
g. Pipeline characteristic resistance.
h. Potential shifts.
i. Current of anode.
j. Requirement of total anode.
k. Radius and distance of anode.
l. Resistance of single anode.
m. Interference factor of anode.
n. Groundbed resistance
o. Wire resistance.
p. Voltage losses of wire
q. Requirement voltage of rectifier.
r. Rectifier design.

#### 2.5.2. Experimental of Speciment Test

a. Data collection

The choice of method is by data collection strategy with many variables such as data of pipeline and fluida, tools, kind of anode, standard of design, protecting criteria, survey of soil resistivity.

b. Specimen data

Specimen data can help confirm the identity and age of cathodic protection design, provide information about the design where has to build, such as :

1) Pipeline

Carbon steel with classification from spiral pipe seamless ASTM A106 Grade B. Long pipeline 0,5 m ; outside diameter 0,048 m; thickness 0,0037 m; resistance 3,48 x $10^{-4}$ Ω-m.

2) Anode.

Carbon graphite; turbular ; long = 0,01 m; Diameter 0,036 m; current density 2,5-10 A/ $m^2$ ; consumption rate 0,1-1 kg/(A.year).

3) Coating data.

Coaltar epoxy cure polyamide with specification Hot Applied mill coated pipe ; 25 °C for temperature; stage destruction 5-65 % per year.

c. Tools

The Tools are used for research such as transformer rectifier, multimeter, soil resistivity meter, accumulator, $Cu/CuSO_4$ for referensial anode.

d. Planning phase

e. Test phase

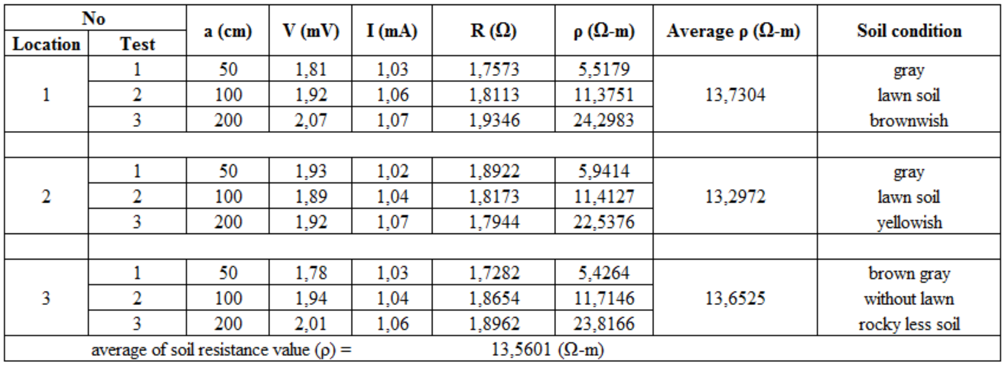
## 3. Result

This section shows the result of numerical calculation and design of fuel pipeline distribution. It includes the design of pipeline, criteria of coating selection, voltage requirement for rectifier design.

### *3.1. Soil Condition*

Measurement of soil condition is used for the control of corrosion of buried structure. It is used for finding the value of soil resistivity. It is used both for estimation of expected corrosion rates and for the design of cathodic protection systems.

Measurement of soil condition is done on 3 (three) locations. Determination of location is based on soil quality, soil structure and distance from the sea. In every location, measurement has done three times with distance variation among pins 0,5 metre, 1 metre and 1,5 metre, voltage source from accumulator 12 volt 9 ampere DC. The result shows 13,56 Ω-m for soil resistance.

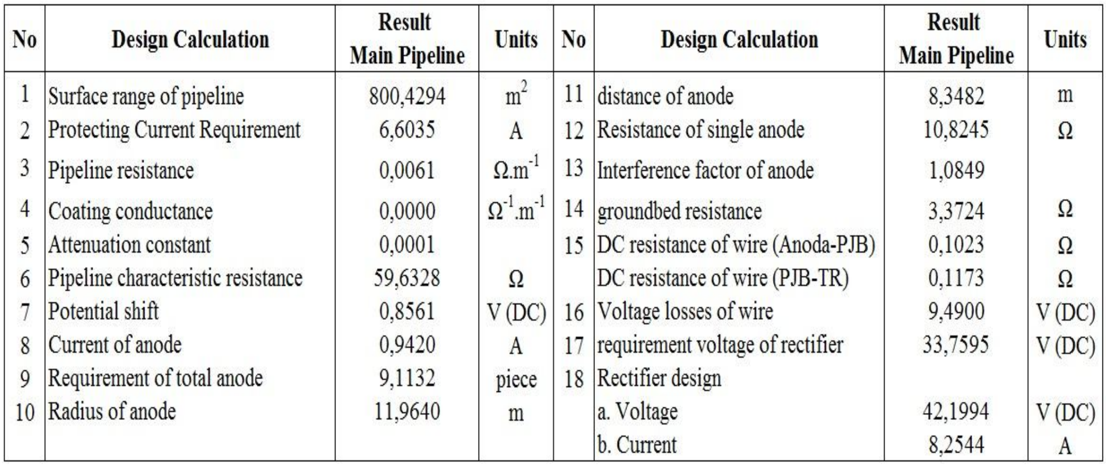


| No | | a (cm) | V (mV) | I (mA) | R (Ω) | ρ (Ω-m) | Average ρ (Ω-m) | Soil condition |
|---|---|---|---|---|---|---|---|---|
| Location | Test | | | | | | | |
| 1 | 1 | 50 | 1,81 | 1,03 | 1,7573 | 5,5179 | 13,7304 | gray |
| | 2 | 100 | 1,92 | 1,06 | 1,8113 | 11,3751 | | lawn soil |
| | 3 | 200 | 2,07 | 1,07 | 1,9346 | 24,2983 | | brownwish |
| | | | | | | | | |
| 2 | 1 | 50 | 1,93 | 1,02 | 1,8922 | 5,9414 | 13,2972 | gray |
| | 2 | 100 | 1,89 | 1,04 | 1,8173 | 11,4127 | | lawn soil |
| | 3 | 200 | 1,92 | 1,07 | 1,7944 | 22,5376 | | yellowish |
| | | | | | | | | |
| 3 | 1 | 50 | 1,78 | 1,03 | 1,7282 | 5,4264 | 13,6525 | brown gray |
| | 2 | 100 | 1,94 | 1,04 | 1,8654 | 11,7146 | | without lawn |
| | 3 | 200 | 2,01 | 1,06 | 1,8962 | 23,8166 | | rocky less soil |
| average of soil resistance value (ρ) = | | | | 13,5601 (Ω-m) | | | | |

Table 2: Result of Soil Resistance

### 3.2. Calculation Design

Result of protected current requirement for fuel pipeline distribution system is 6,6035 A with surface range of pipeline will be protecting 800,429 m$^2$, and 0,825 µA/cm$^2$ for current density ($I_{corr}$).

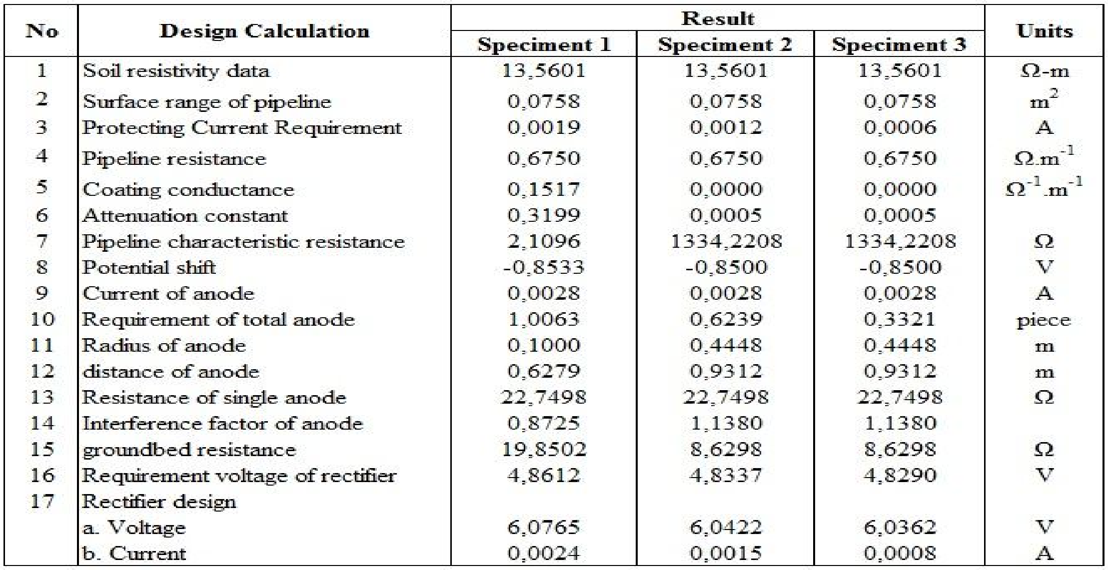


| No | Design Calculation | Result Main Pipeline | Units | No | Design Calculation | Result Main Pipeline | Units |
|---|---|---|---|---|---|---|---|
| 1 | Surface range of pipeline | 800,4294 | m$^2$ | 11 | distance of anode | 8,3482 | m |
| 2 | Protecting Current Requirement | 6,6035 | A | 12 | Resistance of single anode | 10,8245 | Ω |
| 3 | Pipeline resistance | 0,0061 | Ω.m$^{-1}$ | 13 | Interference factor of anode | 1,0849 | |
| 4 | Coating conductance | 0,0000 | Ω$^{-1}$.m$^{-1}$ | 14 | groundbed resistance | 3,3724 | Ω |
| 5 | Attenuation constant | 0,0001 | | 15 | DC resistance of wire (Anoda-PJB) | 0,1023 | Ω |
| 6 | Pipeline characteristic resistance | 59,6328 | Ω | | DC resistance of wire (PJB-TR) | 0,1173 | Ω |
| 7 | Potential shift | 0,8561 | V (DC) | 16 | Voltage losses of wire | 9,4900 | V (DC) |
| 8 | Current of anode | 0,9420 | A | 17 | requirement voltage of rectifier | 33,7595 | V (DC) |
| 9 | Requirement of total anode | 9,1132 | piece | 18 | Rectifier design | | |
| 10 | Radius of anode | 11,9640 | m | | a. Voltage | 42,1994 | V (DC) |
| | | | | | b. Current | 8,2544 | A |

Table 3: Main Pipeline Result Data

### 3.3. Speciment Value

a. Numerical Calculation



| No | Design Calculation | Result | | | Units |
|---|---|---|---|---|---|
| | | Speciment 1 | Speciment 2 | Speciment 3 | |
| 1 | Soil resistivity data | 13,5601 | 13,5601 | 13,5601 | Ω-m |
| 2 | Surface range of pipeline | 0,0758 | 0,0758 | 0,0758 | m$^2$ |
| 3 | Protecting Current Requirement | 0,0019 | 0,0012 | 0,0006 | A |
| 4 | Pipeline resistance | 0,6750 | 0,6750 | 0,6750 | Ω.m$^{-1}$ |
| 5 | Coating conductance | 0,1517 | 0,0000 | 0,0000 | Ω$^{-1}$.m$^{-1}$ |
| 6 | Attenuation constant | 0,3199 | 0,0005 | 0,0005 | |
| 7 | Pipeline characteristic resistance | 2,1096 | 1334,2208 | 1334,2208 | Ω |
| 8 | Potential shift | -0,8533 | -0,8500 | -0,8500 | V |
| 9 | Current of anode | 0,0028 | 0,0028 | 0,0028 | A |
| 10 | Requirement of total anode | 1,0063 | 0,6239 | 0,3321 | piece |
| 11 | Radius of anode | 0,1000 | 0,4448 | 0,4448 | m |
| 12 | distance of anode | 0,6279 | 0,9312 | 0,9312 | m |
| 13 | Resistance of single anode | 22,7498 | 22,7498 | 22,7498 | Ω |
| 14 | Interference factor of anode | 0,8725 | 1,1380 | 1,1380 | |
| 15 | groundbed resistance | 19,8502 | 8,6298 | 8,6298 | Ω |
| 16 | Requirement voltage of rectifier | 4,8612 | 4,8337 | 4,8290 | V |
| 17 | Rectifier design | | | | |
| | a. Voltage | 6,0765 | 6,0422 | 6,0362 | V |
| | b. Current | 0,0024 | 0,0015 | 0,0008 | A |

Table 4: Result of Numerical Calculation Specimen

### b. Experimental Specimen Test

| Day | Current (mA) | | |
|---|---|---|---|
| | Speciment 1 | Speciment 2 | speciment 3 |
| 1 | 1,52 | 0,96 | 0,37 |
| 2 | 1,53 | 1,05 | 0,54 |
| 3 | 1,71 | 1,09 | 0,56 |
| 4 | 1,76 | 1,11 | 0,59 |
| 6 | 1,91 | 1,12 | 0,62 |
| 8 | 1,91 | 1,13 | 0,62 |
| 10 | 1,91 | 1,14 | 0,62 |
| 12 | 1,91 | 1,14 | 0,62 |
| 14 | 1,91 | 1,14 | 0,62 |
| 17 | 1,91 | 1,14 | 0,62 |

*Table 5: Result of Specimen Test*

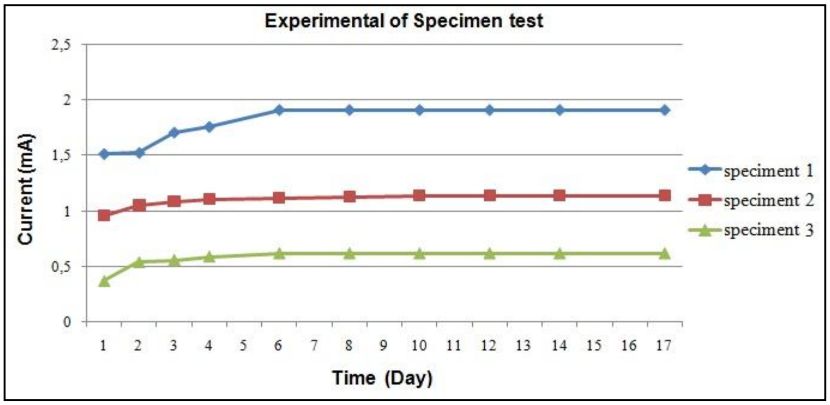


*Figure 2: Result of Specimen Current*

### c. Value of Corrosion Rate

| Day | Value of Corrotion Rate (mpy) | | |
|---|---|---|---|
| | Speciment 1 | Speciment 2 | Speciment 3 |
| 1 | 0,6132 | 0,3873 | 0,1493 |
| 2 | 0,6172 | 0,4236 | 0,2178 |
| 3 | 0,6898 | 0,4397 | 0,2259 |
| 4 | 0,7100 | 0,4478 | 0,2380 |
| 6 | 0,7705 | 0,4518 | 0,2501 |
| 8 | 0,7705 | 0,4558 | 0,2501 |
| 10 | 0,7705 | 0,4599 | 0,2501 |
| 12 | 0,7705 | 0,4599 | 0,2501 |
| 14 | 0,7705 | 0,4599 | 0,2501 |
| 17 | 0,7705 | 0,4599 | 0,2501 |

*Table 6: Result of Corrosion Rate*

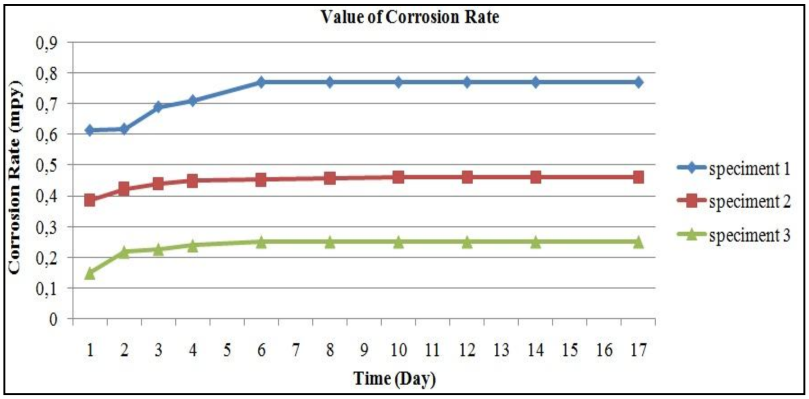


*Figure 3: Corrosion Rate Speciments.*

## 4. Discussion

### *4.1. Comparison of Value of Current between Theoritical and Experimental Test*

| No | Name | Speciment 1 (Uncoating) | Speciment 2 (single coating) | speciment 3 (double Coating) | Units |
|---|---|---|---|---|---|
| 1 | Theoritical Current | 1,8958 | 1,1754 | 0,6256 | mA |
| 2 | Experimental Current | 1,91 | 1,14 | 0,62 | mA |

*Table 7: Value of Theoritical and Experimental Current*

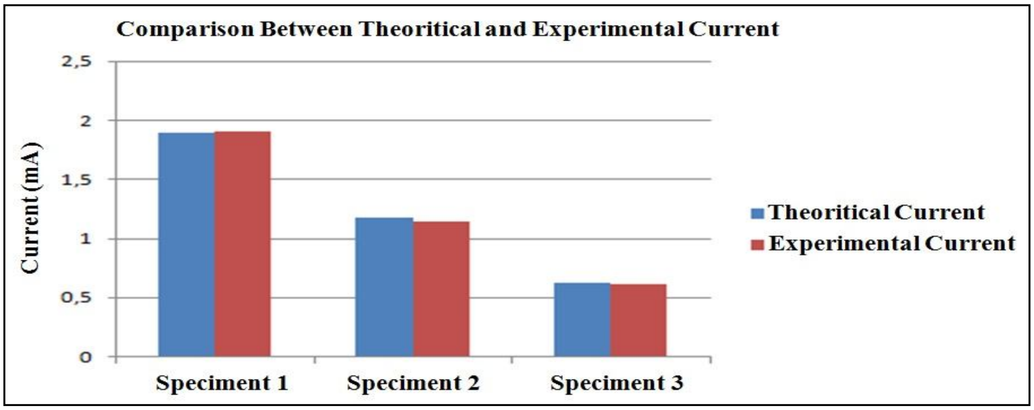


*Figure 4: Comparison of Theoritical and Experiment Current*

### *4.2. Comparion of Current Density and Corrosion Rate between Speciment Pipeline and Main Pipeline*

| Speciment | Coating Condition | Current | | Current Density |
|---|---|---|---|---|
| | | (mA) | (μA) | (μA/cm$^2$) |
| 1 | Uncoating | 1,91 | 1910 | 2,5187 |
| 2 | Single coating | 1,14 | 1140 | 1,5033 |
| 3 | double coating | 0,62 | 620 | 0,8176 |

*Table 8: Value of Current Density*

| Speciment | Coating Condition | Current Density (μA/cm$^2$) | Current value of main pipeline | |
|---|---|---|---|---|
| | | | (μA) | (A) |
| 1 | uncoating | 2,5180 | $20,161 \times 10^6$ | 20,1609 |
| 2 | single coating | 1,5033 | $12,033 \times 10^6$ | 12,0332 |
| 3 | double coating | 0,8176 | $6,544 \times 10^6$ | 6,5444 |

*Table 9: Current Value of Main Pipeline with Coating Condition*

| Name | Current value of main pipeline | | Current density | Corrosion rate | Criteria |
|---|---|---|---|---|---|
| | (A) | (μA) | (μA/cm$^2$) | (mpy) | |
| Theoritical Current | 6,6035 | 6,6035 x 106 | 0,8250 | 0,2524 | Outstanding |
| Experimental Current | 6,5444 | 6,544 x 106 | 0,8176 | 0,2501 | Outstanding |

*Table 10: Value of Corrosion Rate and Criteria*

Result of corrosion rate is regarded by pipeline surface range that will be protected and lifetime of pipeline. At the main pipeline 800,429 $m^2$ for surface range, it has corrosion rate value 0,253 mpy and from experimental pipeline 0,2501 mpy, with clasification of outstanding.

## 5. Conclusion

The pipeline design has 800,429 $m^2$ for surface ranging value. This experiment has 3 specimen materials tests with different various coating. So, the experiment result shows the value of current from theoritical calculation and experiment by specimens test. The result of specimen applied from theoritical calculation presents specimen 1 with value 1,89 x $10^{-3}$ A(DC), specimen 2 presents 1,175 x $10^{-3}$ A(DC) and specimen 3 shows 6,256 x $10^{-4}$ A(DC). The result from value of experiment by specimens test shows specimen 1 with value 1,91 x $10^{-3}$ A(DC), specimen 2 shows 1,14 x $10^{-3}$ A(DC) and specimen 3 presents 6,2 x $10^{-4}$ A(DC). So, the best current value that approach from theoritical calculation is specimen material 3 with twice coating variant. It has current value 6,2 x $10^{-4}$ A and 0,25 mpy for corrosion rate. The result shows that design of impressed current cathodic protection on fuel distribution pipeline system required voltage 33,759 V(DC), protection current 6,6035 A(DC) by theoritical calculation and 6,544 A(DC) from experiment of specimen test. The corrosion rate was observed with 0,25 mpy. The design of Transformer Rectifier needs 45 Volt (DC), current 10 A(DC) with loaded work 70%.

## 6. Acknowledement

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