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# Applied of Impressed Current Cathodic Protection Design For Fuel Pipeline Network at Naval Base

**A. K. Susilo*, A. Ahmadi, O. S. Suharyo and P. Pratisna**

* *ku2h_lagi@yahoo.com*

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**Indonesian Naval Technology College, Bumimoro-Morokrembangan, Surabaya, Indonesia.**

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***Abstract:*** *Indonesian Navy (TNI AL) is the main component for Maritime Security and Defence. Because of that, TNI AL needs Indonesian Warship (KRI) to covered Maritime area. The main requirement from KRI is fulfilled by demand. To pock of fuel demand from KRI at Naval Base, it needs a new pipeline of fuel distribution network system. The pipeline network 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 pipeline network 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. Transformer Rectifier design needs requirements 45 V with 10 A for current. This research result can be made as literature and standardization for Indonesian Navy in designing the Impressed Current Cathodic Protection for fuel distribution pipeline network system.*

***Keywords:*** *Pipeline Network System, Corrosion, Cathodic Protection, ICCP, Rectifier*

## 1. INTRODUCTION

Indonesian Navy (TNI AL) is the main component for Maritime Security and Defence. Because of that, TNI AL needs Indonesian Warship (KRI) to covered Maritime area. The main requirement from 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 at warship.

With the condition background what are demanded from KRI, it is urgent to make design of fuel pipeline distribution network system from metal materials to pock of fuel demand from KRI at Naval Base for supporting warfare alert, basic training and operation activities at sea, but the pipeline network 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 network system needs protection from corrosion that can applied underground. The corrosion of underground structure is a very widespread problem (Al-Sultani, et al., 2012). Structure such as natural gas, crude oil pipelines, and water are only some of the many structures reported to have been affected by soil corrosion (Al-Sultani, et al., 2012).

In today's regulated environment, a method to protect 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, et al., 2012). It is commonly used in the protection of the exterior surfaces of pipelines (Kakuba, 2005). There are two types of applying cathodic protection system, namely Sacrificial Anode Cathodic Protection (SACP) and Impressed Current Cathodic Protection (ICCP) (Al-Himdani, et al., 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 (Choi, et al., 2016). 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, et al., 2016).

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 network system at Naval base, and to analyze corrosion rate from pipeline specimen test. Boundary of problem in this paper is ICCP method applied in surfaces of pipeline, soil chemical anaylis such as pH, Sulphate and Cloride content is ignored, coating is in good condition.

The inscriptive benefit from this paper is a literature for Indonesia Navy about the design of fuel distribution pipeline system in Naval base. It can be made as standarization for design of ICCP at fueled pipeline in Naval base.

This paper has many literatures to support the research, such as literature about corrosion control, cathodic protection and impressed current (ICCP). Literature of paper about corrosion control likes Corrosion Protection System in Offshore Structure (Ivanov, 2016). Synergic effect of Thiomalic acid and Zinc ions in Corrosion control of Carbon Steel in Aqueous Solution (Ramesh, et al., 2014). Reduction of Corrosion Process in Steel Bars Using Inhibitor (Zubaidy, et al., 2012). Green Inhibitor for Corrosion Protection of Metals and Alloys : An Overview (Rani, et al., 2011). Corrosion control in Oil and Gas Pipeline (Enani, 2016). Interactions of Corrosion Control and Biofilm on Lead and Copper in Premise Plumbing (Payne, 2013). Corrosion Control by Green Solution – An Overview (Raja, et al., 2014). Solutions to Corrosion Caused by Agricultural Chemicals (Eker, et al., 2005). Corrosion Protection of Steel Pipelines Againts CO2 Corrosion – A Review (El-Lateef, et al., 2012). Corrosion Control Approach Using Data Mining (Dapiap, et al., 2015).

Paper literature about cathodic protection such as Protect of Underground Oil Pipelines by Using (Al-Sn-Zn) as Sacrificial Anode in Al-Qasim Region (Al-Sultani, et al., 2012). Efficiency of Corrosion Inhibitors on Cathodic Protection System (Briggs, et al., 2014). (Mainier, et al., 2014). Modelling Cathodic Protection for Pipeline Network (Riemer, 2000). Cathodic Protection of an underground Pipeline by Photovoltaic Power System using Intelligent Method (Javadi, et al., 2104). The effect of Cathodic Protection System by Means of Zinc Sacrifial Anode on Pier in Korea (Jeong, et al., 2014). Cathodic Protection of Steel in Concrete Using Conductive Polymer Overlays (A.S.S.Sekar, et al., 2007). Interaction Between Cathodic Protection and Microbially Influenced Corrosion (Masli, 2011). Use of Sacrifial Anode for Corrosion Protection of Tradition Well Cover (Olusunle, et al., 2015). Cathodic Protection of Onshore Buried Pipelines Considering Economic Feasibility and Maintenance (Choi, et al., 2016).

Paper literature explains about ICCP is Shipboard Impressed Current Cathodic Protection System (ICCP) Analysis (Hogan, et al., 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, et al., 2014). Assessing the long term benefits of Impressed Current Cathodic Protection (Christodoulou, et al., 2010). ICCP cathodic protection of tanks with photovoltaic power supply (Janowski, et al., 2016). 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, et al., 2016). The application of impressed current cathodic protection to historic listed reinforced concrete and steel framed structures (Broomfield, 2004).

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. MATERIAL/METHODOLOGY

### 2. 1. Corrosion

Corrosion is defined as the destruction or deterioration of material because of reaction with its environment (Fontana, 1987). 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).

Important types of corrosion are general attack corrosion, metal attack corrosion, galvanic corrosion, environmental cracking, flow assisted corrosion, intragranular, fretting corrosion and high temperature corrosion (Kulkarni, 2015).

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). Corrosion proccess develop fast after disruption of the protective barrier and are accompanied by a number of reactions that change the composition and properties of both the metal surface and the local environment, for example formation of oxides, diffussion of metal cations into the coating, local pH changes and electrochemical potential (Rani, et al., 2011).

$$Fe \rightarrow Fe^{2+} + 2e^{-} \quad (1)$$

$$O_2 \rightarrow 2H_2O^{+} + 4e^{-} \quad (2)$$

$$2Fe + O_2 + 2H_2O \rightarrow 2Fe_2 + 4OH^{-} \quad (3)$$

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 (Peabody, 2001). 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 (Peabody, 2001). 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).

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

### 2. 2. 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. CP is a method to reduce corrosion by minimizing the difference in potential between anode and cathode (Agarwal, et al., 2015). Cathodic protection is often applied to coated structures, with the coating providing the primary form of corrosion protection (Roberge, 1999). 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).

There are two main types of cathodic protection systems; there are impressed current and sacrificial anode. Both types of cathodic protection have anodes, a continuous electrolyte from the anode to the protected structure, and an external metallic connection (wire) (Agarwal, et al., 2015).

**2. 3. 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).

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 (Roberge, 1999). Other power sources include fuel or gas driven generators, thermoelectric generators and solar and wind generators (Roberge, 1999). 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 (Roberge, 1999) :

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 (Roberge, 1999) :

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. 4. 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).

$$Corrosion\ rate = K\frac{Icorr\ x\ E}{D} \quad (4)$$

**2. 5. Method of Research**

This paper shows both experimental from speciment test and studied in detail theoritical calculation design of ICCP. The theoritical result

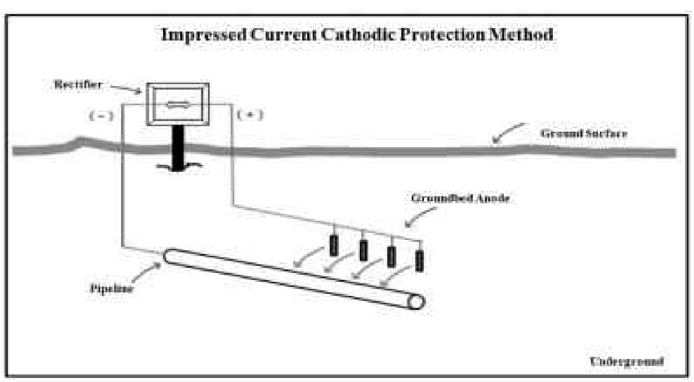


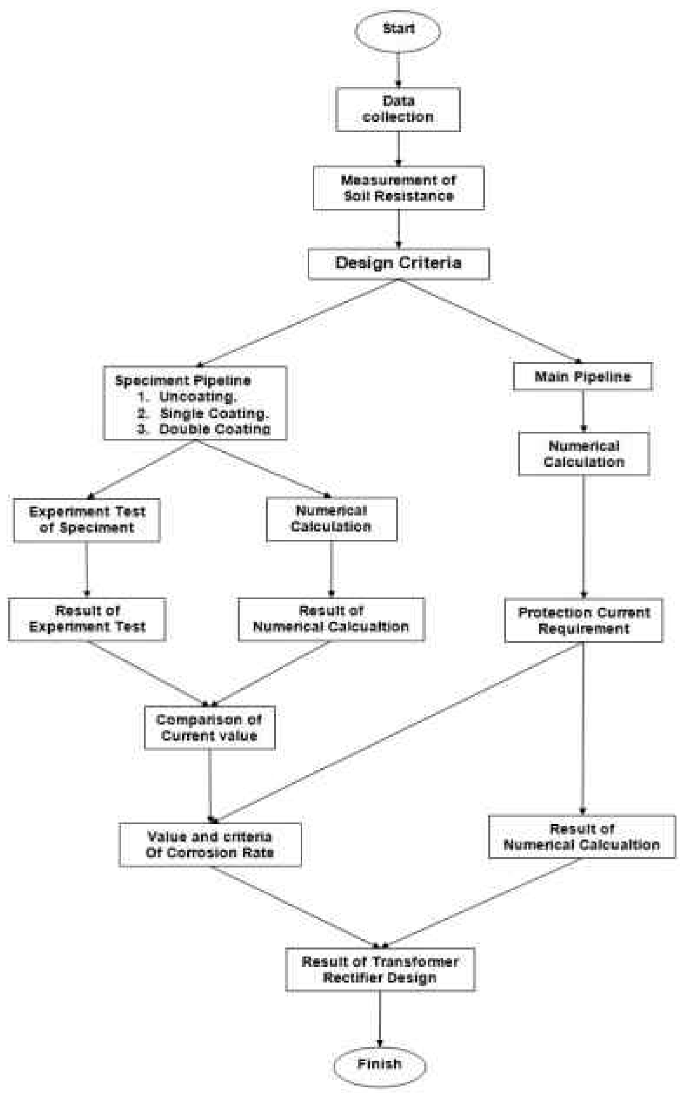

**Fig. 1.** ICCP Method

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

| Relative Corrosin Resistance | Approximate Metric Equivalent | | | | |
|---|---|---|---|---|---|
| | 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 |

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. Flowchart Diagram***



***2. 5. 2. Data Collection***

a. Main pipeline network data.

1) Pipeline.

Carbon steel with classification from spiral pipe seamless ASTM A106 Grade B. Long pipeline 1163.99 m ; outside diameter 0,219 m; thickness 0.00818 m; resistance $3.48*10^{-4}$ Ω-m.

2) Anode.

Carbon graphite; turbular ; long=1m; Diameter 0.06 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.

b. Speciment data.

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 $3.48*10^{-4}$ 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.

**2. 5. 3. Theoritical Calculation Design**

Theoritical 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.

2.5.4 Experimental of Speciment Test

a. Tools

The Tools are used for research such as transformer rectifier, multimeter, soil resistivity meter, accumulator, Cu/CuSO4 for referensial anode.

b. Planning phase.

1) Survey of soil resistance with Wenner Method.

2) Cable laying.

3) Pipe painting.

c. Test phase.

1) Early experiment test.

2) Continuing experiment test.

**3. RESULT**

This section shows the result of theoritical calculation, experimental speciment test 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

**Table 2.** Result of Soil Resistance

| No | | a (cm) | V (mV) | I (mA) | R (Ω) | ρ (Ω-m) | Average ρ (Ω-m) | Soil condition |
|---|---|---|---|---|---|---|---|---|
| Location | Test | | | | | | | |
| 1 | 1 | 50,0000 | 1,8100 | 1,0300 | 1,7573 | 5,5179 | 13,7304 | gray |
| | 2 | 100,0000 | 1,9200 | 1,0600 | 1,8113 | 11,3751 | | lawn soil |
| | 3 | 200,0000 | 2,0700 | 1,0700 | 1,9346 | 24,2983 | | brownwish |
| | | | | | | | | |
| 2 | 1 | 50,0000 | 1,9300 | 1,0200 | 1,8922 | 5,9414 | 13,2972 | gray |
| | 2 | 100,0000 | 1,8900 | 1,0400 | 1,8173 | 11,4127 | | lawn soil |
| | 3 | 200,0000 | 1,9200 | 1,0700 | 1,7944 | 22,5376 | | yellowish |
| | | | | | | | | |
| 3 | 1 | 50,0000 | 1,7800 | 1,0300 | 1,7282 | 5,4264 | 13,6525 | brown gray |
| | 2 | 100,0000 | 1,9400 | 1,0400 | 1,8654 | 11,7146 | | without lawn |
| | 3 | 200,0000 | 2,0100 | 1,0600 | 1,8962 | 23,8166 | | soil less rocky |
| average of soil resistance value (ρ) = | | | | | 13,5601 (Ω-m) | | | |

(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.

### 3. 2. Theoritic Calculation Design of Main Pipeline Network.

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 $\mu A/cm^2$ for current density ($I_{corr}$).

### 3. 3. Speciment Value

a. Theoritic calculation speciment.

Base theoritic calculation table upon, available current difference on each pipeline criteria. Pipeline with double coating has smaller about current value, meanwhile pipeline without coating has greater about current value.

**Table 3.** Main Pipeline Result Data

| 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 | $\Omega.m^{-1}$ | 13 | Interference factor of anode | 1,0849 | |
| 4 | Coating conductance | 0,0000 | $\Omega^{-1}.m^{-1}$ | 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 4.** Result of Theoritic Calculation Specimen

| 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 | $\Omega.m^{-1}$ |
| 5 | Coating conductance | 0,1517 | 0,0000 | 0,0000 | $\Omega^{-1}.m^{-1}$ |
| 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 |

b. Experimental Specimen Test.

For experiment speciment test, previously was taken sample outgrows current point that issued on each speciment pipeline until 17 days. The result is gotten from electricity source the through anode (graphite) and input goes to cathode (pipeline). The result current views table 5.

**Table 5.** Result of 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 |

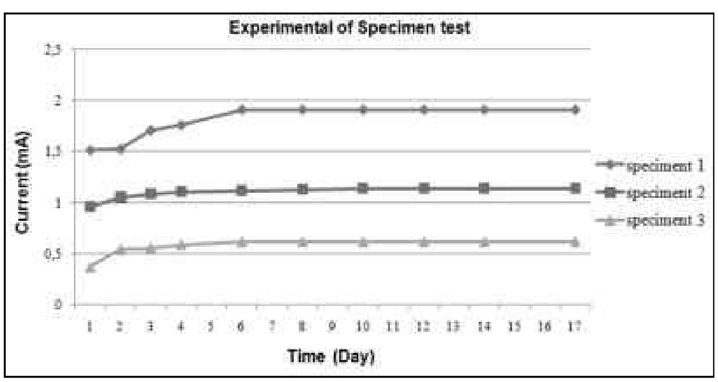



**Fig. 2.** Result of Specimen Current

c. Value of Corrosion Rate

The value of corrosion rate can nake basis to know estimate of design ICCP will be used.

The result showed that design of Impressed Current Cathodic Protection on fuel distribution pipeline network 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. Transformer Rectifier design needs requirements 45 V with 10 A for current.

**Table 5.** Result of 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 |

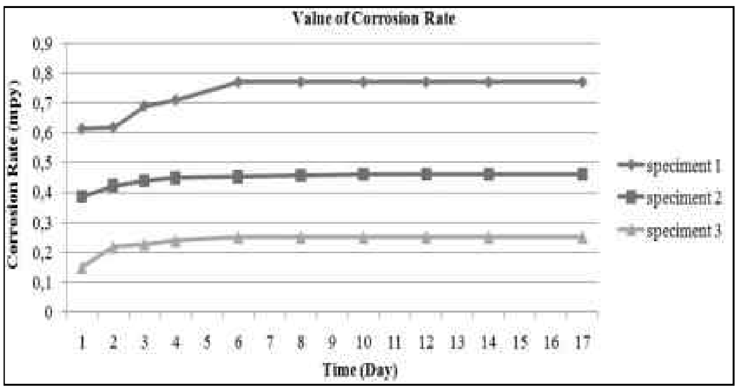



**Fig. 3.** Corrosion Rate Speciments.

## 4. DISCUSSION

### 4. 1. Comparison of Current Value between Theoritical and Experimental Test

Base of data table and figure upon, value of theoritical current to experiment current on speciment 1 that has increase of 1,896 mA becomes 1,91 mA. Whereas on speciment 2 and 3, value of current point has litte decrease. On speciment 2 decreases of 1,175 mA becomes 1,14 mA. On speciment 3 decreases of 0,626 mA becomes 0,62 mA.

**Table 7.** Value of Theoritical and Experimental Current

| 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 |

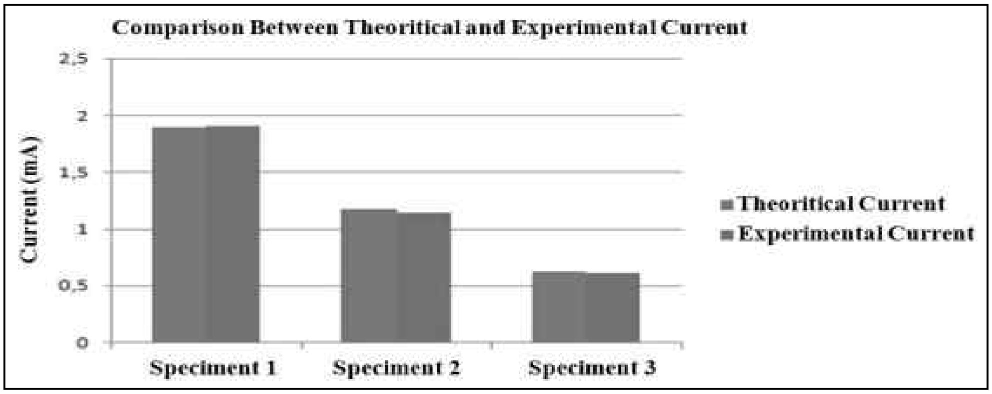



**Fig. 4.** Comparison of Theoritical and Experiment Current

**4. 2. Comparison of Current Density and Corrosion Rate between Speciment Pipeline and Main Pipeline.**

Result of current value of main pipeline comes from calculation current density from speciment pipeline and surface range at main pipeline data.

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 both is outstanding.

**Table 8.** Value of Current Density

| Speciment | Coating Condition | Current (mA) | Current (μA) | Current Density (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 9.** Current Value of Main Pipeline from Speciment Test

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

**Table 10.** Value of Corrosion Rate and Criteria

| Name | Current value of main pipeline (A) | Current value of main pipeline (μA) | Current density (μA/cm$^2$) | Corrosion rate (mpy) | Criteria |
|---|---|---|---|---|---|
| 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 |

## 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 $1.89*10^{-3}$ A(DC), specimen 2 presents $1.175*10^{-3}$ A(DC) and specimen 3 shows $6.256*10^{-4}$ A(DC). The result from value of experiment by specimens test shows specimen 1 with value $1.91*10^{-3}$ A(DC), specimen 2 shows $1.14*10^{-3}$ A(DC) and specimen 3 presents $6.2*10^{-4}$ A(DC). So, the best current value that approach from theoritical calculation is specimen material 3 with twice coating variant. It has current value $6.2*10^{-4}$ 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%.

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## REFERENCES

1. Roberge, P. R., "Handbook of Corrosion Engineering". Mc Graw Hill Company, USA, 1999.
2. Al-Sultani, Khadim F. and Nabat, J. N., "Protect of Underground Oil Pipelines by Using (Al-Sn-Zn) as Sacrificial Anode in Al-Qasim Region". Journal of American Science, 2012, 158-165.
3. Parker, M. E., "Pipeline Corrosion and Cathodic Protection". Gulf Professional , Houston, 1999.
4. Nguyen, C. V., "The Performance of Carbon Fibre Composites as ICCP Anodes for AI". ISRN Corrosion, 2012, 9.
5. Kakuba, G., "The Impressed Current Cathodic Protection System". Technishce Universiteit Eindhoven, Eindhoven, 2005.
6. Al-Himdani, F. F. Mahdi, W. I. and Khuder, A. W. H. "Corrosion Protection of Coated Steel Pipeline Structures using CP Technique". Journal of Engineering and Development, 2005.
7. Choi, B. Y., Kim, J. K. and Oh, J. S., "Cathodic Protection of Onshore Buried Pipelines Considering Economic Feasibility and Maintenance". Journal of Advanced Research in Ocean Engineering, 2016.
8. Ivanov, H., "Corrosion Protection System in Offshore Structure. University of Akron". Ohio, 2016.
9. Ramesh, S. P. M. and Periasamy, V., "Synergic effect of Thiomalic acid and Zinc ions in Corrosion control of Carbon Steel in Aqueous Solution". 2014, Research Journal of Chemical Sciences, 2014, 41-49.
10. Zubaidy, E. A. H. and Tamimi, A. A., "Reduction of Corrosion Process in Steel Bars Using Inhibitor". International Journal of Electrochemical Science , 2012, 6472-6488.
11. Rani, B. E. A. and Basu, B. B. J., "Green Inhibitor for Corrosion Protection of Metals and Alloys: An Overview". International Journal of Corrosion, 2011.
12. Enani, J., "Corrosion Control in Oil and Gas Pipeline". International Journal of Scientific & Engineering Research, 2016, 1161-1164.
13. Payne, S. J. O., "Interactions of Corrosion Control and Biofilm on Lead and Copper in Premise Plumbing". Dalhousie University, Halifax, 2013.
14. A. S. Raja et al., Corrosion Control by Green Solution – An Overview. International Journal of Advanced Research in Chemical Science, 2014, 10-21.
15. Eker, B. and Yuksel, E., "Solutions to Corrosion Caused by Agricultural Chemicals". Trakia Journal of Sciences, 2005, 1-6.
16. El-Lateef, Hany M. A., "Corrosion Protection of Steel Pipelines Againts $CO_2$ Corrosion – A Review". Chemistry Journal, 2012, 52-63.
17. S. Dapiap, G. Wajiga, M Egwurube, M. Kadzai, and Nathaniel., "Corrosion Control Approach Using Data Mining". International Journal of Computer Science & Information Technology,

2015, 53-71.

18. Briggs, T. and Eseonu, Y. M.., "Efficiency of Corrosion Inhibitors on Cathodic Protection System". International Journal of Engineering Trends and Technology (IJETT), 2014.
19. Mainier, F. B., Leta, F. R. and Feliciano, F. F., "Application of Anticorrosive Techniques Compatible with the Environment to Engineering Education". American Journal of Environmental Engineering, 2014, 176-181.
20. Riemer, D. P., "Modelling Cathodic Protection for Pipeline Network". University of Florida, Florida, USA, 2000.
21. Javadi, M., Javidan, J. and Salimi, M., "Cathodic Protection of an underground Pipeline by Photovoltaic Power System using Intelligent Method". International Journal of Renewable Energy Research, 2014, 267-274.
22. Jeong, J. A. and Jin, C. K., "The effect of Cathodic Protection System by Means of Zinc Sacrifial Anode on Pier in Korea". Journal of the Korean Society of Marine Engineering, 2014, 1206-1211.
23. Sekar, A. S. S., Saraswathy, V. and Parthiban, G. T., "Cathodic Protection of Steel in Concrete Using Conductive Polymer Overlays". International Journal of Electrochemical Science, 2007, 872-882.
24. Masli, A. B., "Interaction Between Cathodic Protection and Microbially Influenced Corrosion". University of Manchester, Manchester, 2011.
25. Olusunle, Ogundare, Akinribide, and Adebo., "Use of Sacrifial Anode for Corrosion Protection of Tradition Well Cover". International Journal of Engineering and Technology, 2015, 269-274.
26. Hogan, V. G. E., Lucas, K. E. and Wimmer, S. A., "Shipboard impressed current cathodic protection system (ICCP) analysis". WIT Transactions on State of the Art in Science and Engineering, 2005.
27. Bhuiyan, S., "Effectiveness of Impressed Current Cathodic Protection System in Concrete Following Current Interruption". RMIT University, Singapore, 2015.
28. Hashim, M. S, Mohammed, K. A. and Hamadi, N. J., "Modeling and Control of Impressed Current Cathodic Protection (ICCP) System". J. Electrical and Electronic Engineering, Basra, Iraq, 2014.
29. Christodoulou, C., Glass, G., Webb, J., Austin, S. and Goodier, C., "Assessing the long term benefits of Impressed Current Cathodic Protection". Elvesier, 2010.
30. Janowski, M. and Wantuch, A., "ICCP cathodic protection of tanks with photovoltaic supply". SEED, 2016, 10.
31. Balla, E. E. and Rahmat, M. F., "System Identification Modelling and IMC Basic Control of Impressed Current Cathodic Protection Systems". International Journal on Smart Sensing and Intelligent System, 2013.
32. Sada, B. N. A., Sada, Ali, R. S. and Ali, K. A. M., "Identification and Control of Impressed Current Cathodic Protection System", J. Electrical and Electronic Engineering. Iraq, 2016.
33. Broomfield, J. P., "The application of impressed current cathodic". JCSE, 2004.
34. Fontana, M. G., "Corrosion Engineering". McGraw Hill,Inc, Singapore, 1987.
35. Badford, S. A., "Corrosion Control". CASTI, Canada, 2001
36. Peabody, A. W., "Control of Pipeline Corrosion". NACE International, Houston, 2001.
37. Agarwal, S., "Corrosion: A General Review". International Conference of Advance Research and Innovation, 2015, 181-183.
38. Orazem, M. E., "Underline pipeline corrosion". Woodhead Publising, Cambridge, 2014.
39. NACE, "International. NACE Corrosion Engineer's Reference Book". NACE International The Corrosion Society, Houston, 2002.