BACHELOR THESIS - ME 141502

CORROSION RATE ANALYSIS ON CARBON STEEL PIPE, CARBON STEEL PIPE WITH EPOXY COATING, AND GALVANIZED CARBON STEEL PIPE BY ELECTROCHEMICAL METHOD

Revananda Putra Prathama Setyono

NRP 0421 14 4100 0034

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DOUBLE DEGREE PROGRAM

MARINE ENGINEERING DEPARTMENT

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APROVAL FORM

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BACHELOR THESIS

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Engineering Degree in Double Degree of Marine Engineering (DDME) Program
Department of Marine Engineering – Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember
Departement of Maritime Studies
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Surabaya
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July 2018

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DECLARATION OF HONOUR

I hereby who signed below declare that:

This thesis has been written and developed independently without any plagiarism act. All contens and ideas drawn directly from internal and external sources are indicated such as cited sources, literatures, and other professional sources.

Name	: Revananda Putra Prathama Setyono
Student ID Number	: 04211441000034
Thesis Title	: Corrosion Rate Analysis on Carbon Steel Pipe, Carbon Steel Pipe with Epoxy Coating, And Galvanized Carbon Steel Pipe by Electrochemical Method
Departement	: Double Degree of Marine Engineering

Surabaya, July 2018

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ABSTRACT

The seawater is flowing through ballast pumps, main pipelines, and branch pipes. Because of seawater is the most corrosive natural fluid and ballast needs a lot of seawater usage, the risk of corrosion is very high. Therefore, the protective for corrosion is needed to make the system function efficiently. In the shipping world is highly dependent on the steel metal material for the needs of the ship especially for the ballast pipe. This bachelor thesis aims to determine the corrosion resistance with specimen carbon steel pipe, carbon steel pipe with epoxy coating, and galvanized carbon steel pipe with electrochemical method.

The result of the corrosion rate shows the difference on each immersion time. There are 2 times immersion for each experiment specimen 72 hours and 144 hours. For immersion 72 hours of Specimen carbon steel pipe is 0.194746712 mmpy and for 144 hours is 0.28611955 mmpy. The immersion of specimen carbon steel pipe with epoxy coating for 72 hours is 0.018398877 mmpy and for 144 hours is 0.0190332 mmpy. And for the galvanized carbon steel pipe for 72 hours immersion is 0.001825366 mmpy, for the 144 hours is 0.001971516 mmpy.

Keywords: Corrosion Rate, Carbon Steel Pipe, Electrochemical Method

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ANALISA LAJU KOROSI PADA PIPA BAJA KARBON, PIPA BAJA KARBON DENGAN COATING EPOKSI, DAN PIPA BAJA KARBON GALVANIS DENGAN METODE ELEKTROKIMIA

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ABSTRAK

Air laut mengalir melalui pompa balas, pipa utama pada sistem balas, dan pipa cabang pada sistem balas. Karena air laut adalah cairan alami yang paling korosif dan sistem balas membutuhkan banyak penggunaan air laut, risiko terkena korosi sangat tinggi. Oleh karena itu, pelindung korosi diperlukan untuk membuat sistem berfungsi secara efisien. Di dunia pelayaran sangat tergantung pada material besi baja untuk kebutuhan kapal terutama untuk pipa balas. Penelitian ini bertujuan untuk mengetahui ketahanan korosi dengan spesimen pipa baja karbon, pipa baja karbon dengan lapisan epoksi, dan pipa baja karbon galvanis dengan metode elektrokimia.

Hasil laju korosi menunjukkan perbedaan pada setiap waktu perendaman. Ada 2 kali perendaman untuk masing-masing spesimen percobaan 72 jam dan 144 jam. Untuk perendaman 72 jam pada spesimen pipa baja karbon adalah 0,194746712 mmpy dan selama 144 jam adalah 0,28611955 mmpy. Perendaman spesimen pipa baja karbon dengan lapisan epoksi selama 72 jam adalah 0,018398877 mmpy dan selama 144 jam adalah 0,0190332 mmpy. Dan spesimen pipa baja karbon galvanis selama 72 jam perendaman adalah 0,001825366 mmpy, untuk 144 jam adalah 0,001971516 mmpy.

Kata Kunci: Laju Korosi, Pipa Baja Karbon, Metode Elektrokimia

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PREFACE

Alhamdulillah hirabbil ‘alamin a huge thanks to Allah SWT the God almighty who give the intelligent, strength, and favor so the author can finish this bachelor thesis. This bachelor thesis is defined about experiment and analysis of corrosion rate on carbon steel pipe, carbon steel pipe with epoxy coating, and galvanized carbon steel pipe.

On this occasion the author would to express his immeasurable appreciation and deepest gratitude for those who have helped in completing this bachelor thesis:

1. Mama, Papa, brother, and sister who always supporting both mentally, financially, and the prayers were given to the author.
2. Ir. Amiadji, M.Sc. as Supervisor 1.
3. Ir. Tony Bambang Musriyadi, PGD, MMT. as Supervisor 2.
4. Dr. Eng. M. Badrus Zaman, S.T., M.T. as Head Marine Engineering Department FTK-ITS, Surabaya.
5. All of Marine Engineering 2014’s friends who always supporting this bachelor thesis.
6. All of Marine Machinery and System (MMS) friends who always supporting place to live, ideas, and prayer.
7. Franky Yonatan H. and Yudha Kurniawan A. for the ideas of this bachelor thesis.
8. Raka Sukma Purwoto for make this thesis in order and neat.
9. Acis, Sitha, Faisal, Tegar, Obi, and my high school friends who always support the author in all kind of forms.

The author also aware in the writing of this thesis is far from perfection and there are still mistaken in this bachelor thesis because there are still many shortcomings of the author. On writing of this thesis expected to expand knowledge for readers and can be developed for further research.

Surabaya, July 2018

Revananda Putra Prathama S.

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CHAPTER I
INTRODUCTION

1.1. Background

Corrosion is material degradation due to electrochemical reaction of metal material to its environment (Einar Bardal, 2003). Many experts also explain corrosion is decrease in metal quality due to electrochemical reactions with the environment (Trethewey, K. R. and J. Chamberlain, 1991). The environment can be water, air, gas, acid solution, and others (Andi Rustandi, 2008).

In the shipping world is highly dependent on the steel metal material for the needs of the ship especially for the ballast pipe. The resistance of the steel material to the corrosion rate is great concern that seawater is the most corrosive natural fluid, so it is expected that the lifetime of the material will last long due to corrosion attack. Therefore, the electrochemical reaction due to fluid-fed steel leads to corrosion, especially with the use of ships that operate in many marine areas.

The material that is very often used for ship is steel. Similarly, the use of steel materials with galvanized pipe and epoxy pipe. The corrosion rate test is performed by electrochemical using 3 electrode cells, which is a corrosion rate test with the polarization of its free corrosion potential. The results of the test will be obtained a comparison graph of each material and also can be known how long the materials will be replaced.

1.2. Statement of Problems

Based on the background above, the author will be discuss about:

1) How much is the value of the corrosion rate on the test specimen?
2) What is the comparison between carbon steel pipe, galvanized pipe, and pipe with epoxy coating for corrosion protection?
3) Which pipe is the most effective protection from corrosion considering classification of relative corrosion resistance?

1.3. Research Objectives

From the research taken will be determined several objectives of corrosion rate that occur in the pipeline by electrochemical method. The purpose of this research is:

1) To know the value of the corrosion rate occurring on the test specimen.
2) To know the comparison between carbon steel pipe, galvanized pipe, and pipe with epoxy coating for corrosion protection.
3) To know which pipe with the most effective protection from corrosion classification category of relative corrosion resistance.

1.4. Research Limitation

1) The method of calculation is using 3 electrode cells (electrochemical) of corrosion rate with Potensiostat Autolab PGSTAT128N and NOVA software.
2) Corrosion media is aquadest and NaCl with salinity 35%.
3) Epoxy using International INTERTUF 262 red color (code KHA303).

1.5. Research Benefits

1) For Industries:

   Could be considered of pipe that used by ship through by seawater.

2) For Research:
   Helping students to complete the thesis as a reference and increase the knowledge of corrosion rate.

CHAPTER II
LITERATURE STUDY

2.1. Ballast Pipe

System ballast is a system to make position the ship in balanced or suitable position. In general, this system is filling the ballast tank, which is in the double bottom taken from the sea chest with seawater. The seawater is flowing through ballast pumps, main pipelines, and branch pipes. Because of seawater is the most corrosive natural fluid and ballast needs a lot of seawater usage, the risk of corrosion is very high. Therefore, the protective for corrosion is needed to make the system function efficiently.

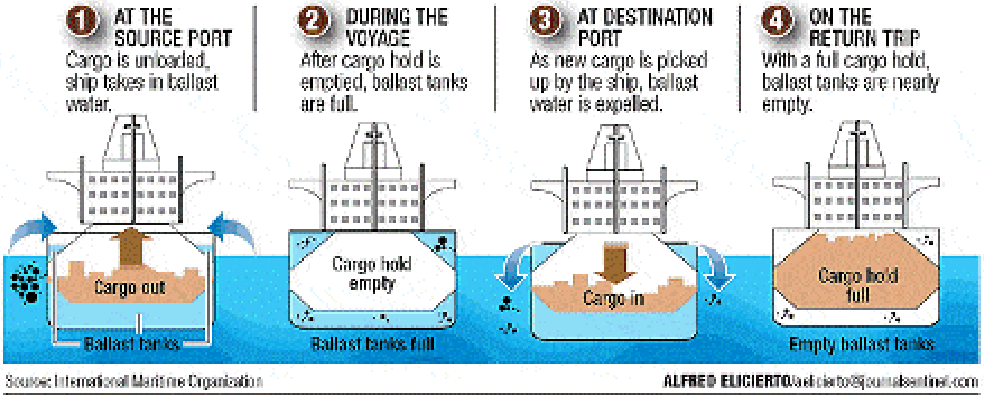

Figure 2. 1 Ballast Water Cycle (Venteville, n.d.)

2.2. Pipe

Pipes are silent ‘workers’, conveying fluids or allowing air to enter or to leave a space and are the means through which many control systems operate. Pipe is a hollow cylindrical bar that can be used for passing or passing liquids, vapors, gases or powdery substances that can be powdered/powder type. For the manufacture of steel pipe can be made with several methods such as seamless pipe, butt welded pipe, and spiral-welded pipe. Pipe making is designed to the needs and the pipe can handle the limit of pressure strength, pipe wall thickness, the temperature of the flowing substance, the type of material related to the corrosion and strength of the pipe.

2.2.1. Carbon Steel Pipe

The main elements of carbon steel are Fe (Ferrum) or iron. In addition, there are also other elements that affect the nature, namely C (Carbon) or carbon. The percentage of carbon in carbon steel material becomes a determinant of the degree of hardness of this material. The higher the amount of carbon, the boiling point for the melting is lower, and vice versa.

Carbon steels consist of iron, less than 1.7% carbon, manganese less than 1.65%, silicon (Si), aluminum (Al), and contaminant boundaries such as sulfur (S), oxygen (O), nitrogen (N), and no minimum limit is specified for elements such as Al, Cr, Co, Ni, Mo, Ni [ASM, ASTM A 941]. There are also types of carbon steel pipe:

1) LCS (Low Carbon Steel):

LCS carbon steels have carbon content below 0.25 percent. Its properties are tough and tough and harder than other carbon steel groups. LCS is often used for car bodies, bridges, pipes, and ships. The yield strength of the LCS carbon steel is 275 Mpa (40,000 Psi). Meanwhile, its tensile strength is 415 and 550 Mpa.

2) MCS (Medium Carbon Steel):

Type MCS carbon steel has a carbon content of 0.25 percent to 0.6 percent. This type of carbon steel can be hardened rapidly by heating. Typically, MCS type carbon steels are used for railroads. Its nature is wear-resistant, very hard, and not tenacious.

3) HCS (High Carbon Steel):

HCS type carbon steels have carbon content of between 0.6 percent and 1.4 percent. This type can be hardened by tempering. Its very hard, brittle, and not tenacious. Typically, HCS carbon steel is used for cutting tools, tool steel, and so on.

2.2.2. Carbon Steel Chemical Grades

Carbon steel is an alloy consisting of iron and carbon. Several other elements are allowed in carbon steel, with low maximum percentages. These elements are manganese, with 1,65% maximum, silicon, with a 0,60% maximum, and copper, with a 0,60% maximum. Other elements may be present in quantities too small to affect its properties. There are four types of carbon steel based on the amount of carbon present in the alloy. Lower carbon steels are softer and more easily formed, and steels with a higher carbon content are harder and stronger, but less ductile, and they become more difficult to weld. Below are the properties of the grades of carbon steel we supply:

- Low Carbon Steel: Composition of 0,05%-0,25% carbon and up to 0,4% manganese. Also known as mild steel, it is a low-cost material that is easy to shape. While not as hard as higher-carbon steels, carburizing can increase its surface hardness.
- Medium Carbon Steel: Composition of 0,29%-0,54% carbon, with 0,60%-1,65% manganese. Medium carbon steel is ductile and strong, with long wearing properties.
- High Carbon Steel: Composition of 0,55%-0,95% carbon, with 0,30%-0,90% manganese. It is very strong and holds shape memory well, making it ideal for springs and wire.

- Very High Carbon Steel: Composition of 0,96%-2,1% carbon. Its high carbon content makes it an extremely strong material. Due to its brittleness, this grade requires special handling.

2.2.3. Carbon Steel Chemical Composition

1) Carbon (C):

Carbon is added to iron to make steel. In its pure form iron is quite soft and adding up to 2% carbon gives it toughness and strength. Structural steels plates typically contain about 0,15 to 0,3% Carbon. As the amount of carbon increases in the steel the strength increases but the ductility decreases. So, iron with a lot of carbon added to it becomes very brittle and is unable to respond elastically to dynamic loading.

2) Silicon (SI):

Silicon is added to carbon steels to help deoxidise. That is the silicon helps to remove bubbles of oxygen from the molten steel. It is also useful in increasing strength and hardness but is less effective than Manganese in doing so. Negatively for many uses it also increases grain size so there is usually an upper limit on it.

3) Manganese (MN):

Manganese is probably the second most important alloying element after carbon on steel. Like Carbon has a large impact on strength, ductility and hardenability. Manganese helps to reduce oxides and also counteract the presence of Iron Sulphide. Steelmakers however had to be careful that the level of Carbon and Manganese doesn’t get too high or the steel becomes too brittle and decreases weldability.

4) Sulphur (S):

Sulphur is another residual element in structural and pressure vessel steels. Sulphur decreases notch impact toughness, reduces weldability and decreases ductility. It generally appears as sulphide inclusions in the steel which decreases its strength.

5) Phosphorous (P):

Phosphorous is normally considered to be an unwanted residual element. This is because most applications require very low or low phosphorus requirements. Phosphorus increases steel embrittlement, which reduces the toughness and ductility of the metal. In uses this generally appears as cracks and fractures. High phosphorus in steel is a contributing factor to HIC cracking in wet H2S environments.

6) Chromium (CR):

Chromium as an alloying element in steel helps to increase its corrosion and oxidation resistant properties. When the % of chromium in the steel exceeds 1.1% a surface layer is formed that helps protect the steel against oxidation.

7) Nickel (NI):

Nickel is used to improve the steels corrosion resistance properties. It is a key component in stainless steels but at the low concentrations found in carbon steels it helps to increase impact strength and hardenability.

8) Nitrogen (N):

Nitrogen is a residual element for hot rolled steel plates. Generally high levels of nitrogen will give the plate inconsistent mechanical properties and make welding more difficult by increasing embrittlement in the heat affected zone (HAZ).

9) Copper (CU):

In structural steels copper is primarily used as an alloying element as it will improve atmospheric corrosion resistance and help paint bond the steel. It also has a small impact on hardenability.

10) Niobium (NB):

Niobium is a key grain refining element in steel production. That is because it makes the grain size smaller it simultaneously improves strength, toughness and ductility.

11) Vanadium (V):

Vanadium when added in the steelmaking process helps to remove oxides and thus increases the yield strength and tensile strength of steel plates.

12) Titanium (TI):

Titanium in steel helps to keep grain size small and also helps manage inclusions by making them rounder.

13) Molybdenum (MO):

Molybdenum is used to increase the strength of boiler and pressure vessel steels at typical boiler operating temperatures of 400°C. Typically it is used in conjunction with Chromium to provide strength and corrosion resistance at high temperature as well as increased creep strength.

14) Boron (B):

Boron is added to fully killed fine grained steel to increase hardenability. This gives a benefit to the yield strength and toughness if the steel is fully hardened before tempering.

15) Zirconium (ZR):

Zirconium is added to steel to modify the shape of inclusions. It helps them to become rounder (as opposed to elongated). The result is that toughness and ductility are improved when the plate is fabricated into a shell.

2.2.4. Galvanized Carbon Steel Pipe

The selection of pipe is often based on the needs and objectives of the installation. Different types and brands are available on the market depending on the function, location, and material. One type of pipe that is popularly used for industry is galvanized pipe. Unlike PVC pipe, galvanized pipe has more advantages and is considered more durable.

Galvanized steel pipe is a kind of pipe made of iron and covered by a protective material made of zinc. The coating is intended to protect the steel from corrosion so that its use is more durable. In the manufacture of galvanized pipe, low carbon steel needs with galvanized coating containing various types of elements in it. In addition to preventing corrosion, the zinc coating on the outside of the pipe can also prolong the life of the tube inside. Since the main element of galvanized pipe is zinc, this type of pipe is recommended for cold-water installation only.

Currently, one of the most popular types of galvanized pipe is the standard and Schedule type. The difference between the two lies in the thickness of the pipe construction; type Schedule 40 level higher thickness and often used for pipe vessels, which repulse also high.

The specimen will be galvanized by hot dip method. Hot dip method is a coating process where the coating metal is heated first to melt, then the metal to be coated which is usually called the base metal is immersed in a galvanized bath which already contains the liquid zinc, so that in a while the metal will be coated by a layer of alloy layer between the metal (zinc) coatings with base metals in the form of chemical bonds that are strong and arranged in layers called phases. Hot dip galvanizing coatings are often referred to as metal coating processes with other more anodic metals in accordance with galvanic series.

The first step is pre-treatment, this step serves to remove acid or base which is impurities attached to the specimen, this is intended to obtain a clean surface conditions and obtained good coating results. The cleaning process can be grouped into two:

1) Physical cleaning process (mechanical):

Physical cleansing can be smoothing the surface by using a grinding machine (sandpaper), which includes smoothing uneven surfaces and removing scratches on the surface of the specimen.

2) Chemical cleaning process:

The chemical cleaning process is the process of cleaning the impurities attached to the surface of the specimen by using chemicals. This cleaning process includes:

a. Degreasing

The process of degreasing is a process that aims to remove dirt, grease, fat, paint and other solid impurities attached to the surface of the specimen. The cleaning process is carried out by using a NaOH solution (caustic soda) at concentrations of 5% - 10% at 70oC - 90oC for about 10 minutes.

b. Rinsing 1

The process of first rinsing aims to clean caustic soda on degreasing processes that are still attached to the surface of the inner specimen by using clean water at room temperature.

c. Pickling

The pickling process aims to remove rust attached to the surface of the specimen by immersion in a solution of HCL (hydrochloric acid) or a solution of H2SO4 (sulfuric acid) at a concentration of 10%-15% for 15-20 minutes.

d. Rinsing II

The second rinsing process aims to clean the HCl or H2SO4 solution attached to the specimen during the pickling process using clean water at room temperature.

e. Fluxing

The fluxing process is an initial coating process using Zinc Ammonium Chloride (ZAC) with concentration 20% - 30% for 5 - 8 minutes. The fluxing process is done with the aim of:

- As a base layer for strengthening the zinc layer during the coating process.
- As the reaction catalyst of Fe-Zn plating.
- To avoid the oxidation process before the galvanizing process is performed.

The fluxing process takes place at a temperature of 60oC-80oC, it is intended that the heat transfer in the specimens is slow and gradual in order to avoid the occurrence of deformation plastic that can disrupt the process of attaching zinc to the workpiece when galvanizing process takes place.

f. Drying

Drying process is a process of drying and preheating by using hot gas temperature of approximately 150oC, the goal is to remove the liquid that may be on the surface of the specimen that can cause a steam explosion during the galvanizing process takes place.

3) Stages of dipping (galvanizing):

Specimens that have pass the preparation stage (pre-treatment) and has been clean of all impurities then the next step is done by the process of dipping (galvanizing). During the galvanizing process takes place, the zinc liquid will coat the steel by forming a layer of zinc steel and then formed a layer that is entirely a zinc element on the outer surface of steel, the solution used is at least 98% pure element of zinc. The immersion stage is carried out for approximately 1.5 minutes at a temperature of 440oC-460oC. The thickness of the zinc coating on coating by hot dip galvanizing method is influenced by surface conditions, duration of immersion, and dipping temperature.

4) Cooling and Final Stages:

a. Cooling phase (quenching):

The cooling stage is performed by dipping the specimen into a sodium cromate solution with a concentration of 0,015% at room temperature or by using water. This process aims to prevent the occurrence of white rust.

b. The final stage (finishing):

The final part of the coating process is to refine a pointy surface caused by the liquid of the dew that wants to drip but has dried first.

2.2.5. Steel Carbon Pipe with Coating

The function of coating is to obtain protection from the corrosion. There are two types of coating, liquid coating (painting) and concrete coating. The function of liquid coating beside used as a decorative, the liquid coating also protected the substance from the corrosion. The advantage of using the liquid coating or painting is easy to use, save more money from the economical, and reliable.

Two parts epoxy coatings are developed for heavy service on metal substrates and use less energy than heat-cured coating powder. The system uses 4:1 by mixing volume ratio, and fast dry provides a tough, UV resistant, excellent hardness shielding layer. Fusion Bonded Epoxy (FBE) Powder Coating is widely used for corrosion protection of steel pipes and also widely used as primers for improving the adhesion of automotive and marine paints especially on metal surfaces where corrosion (rusted) resistance is important.

This type of coating can protect the steel from corrosion for long periods of time, and has protective coating characteristics against seawater, it is suitable to be applied on ship pipe that is passed by seawater and the grade is A972–A972/A972M-99 (Specification for Fusion Bonded Epoxy-Coated Pipe). The epoxy standard is found in the type of paint called primary alkyd, primary metal, primary epoxy, and shop. Basically, this coating can prevent corrosion, it is suitable to apply on pipeline, tank storage and steel structure on the seafront, offshore, and onshore. In the application of this type of coating is not suitable for basic or early painting after blasting. The recommended SSPC is Sa 2.5a and thinner ratio of 10% - 20%, depending on the type of method and application in the field. In terms of price, this type is classified as a standard paint. There also component in paint:

1) Binder

Binder is the main ingredient of paints. Binders are polymers forming a continuous film on the substrate surface.

Binders are responsible for good adhesion of the coating to the substrate. The binder holds the pigment particles distributed throughout the coating. The binder is dispersed in a carrier (water or organic solvent either in molecular form or as colloidal dispersions.

2) Solvent

Solvent (water or organic solvent) is a medium where the binder, pigment and additives are dispersed in molecular form or as colloidal dispersions.

3) Pigment

Pigment is a solid substance dispersed throughout the coating to impart it a color, opacity (hide the substrate surface).

4) Additives

Additives are small amounts of substances modifying the paint properties.

2.3. Epoxy

Applications for epoxy materials are broad-based and include coatings, adhesives and composite materials such as steel carbon. Chemical epoxy allows polymer curing to be produced with a very wide range of properties. The needs of coating are several layers for desire thickness. In this thesis author will be choosing for the maximum thickness for the corrosion protection. Coating with epoxy must be using the painting method with two steps:

2.3.1. Pipe Cleaning and Preparation

Figure 2. 2 Pipe Cleaning and Preparation for Epoxy Coating (Flow, n.d.)

This step serves entire plumbing system drained and dried using dehumidified compressed air. A safe abrading agent is then blown through the pipe system, removing rust, scales and corrosion that have built up over time, while at the same time lightly etching the pipe to prepare for the epoxy coating process. Air is applied once again to remove any remaining garnet.

2.3.2. Epoxy Coating

Figure 2. 3 Epoxy Coating on Pipe (Flow, n.d.)

Optimal internal pipe surface temperature is created prior to epoxy coating. Another air pressure leak test is performed. Conditioned air is then introduced into the pipe to evenly distribute the epoxy coating throughout the piping system. Following the coating application, conditioned, and controlled airflows through the pipes to facilitate epoxy curing.

Figure 2. 4 National Intertuf 262 For Epoxy Specimen

Specification of National Intertuf 262;

Colour : KHA330 – Red

Finish : Matt

Part B (Curing Agent) : KHA 062

Volume Solids : 73% (ISO 3233:1998)

Mix Ratio : 4.00 volume Part A to 1 volume Part B

Typical Film Thickness : 125 microns dry

Method of Application : Air spray, Brush, Roller

Induction Period : Non required

2.4. Corrosion

It is a form of corrosion where corrosion occurs when there is a gap due to merge or unification of two equal metals having different oxygen levels with the outer area. This type of corrosion is usually caused by small holes, and cracks beneath the heads of bolts and rivets.

Corrosion can occur in dry medium with the electrolyte of the soil and also the wet medium with the water electrolyte. For example, corrosion occurring in dry medium is iron metal invasion by oxygen gas (O2) or by sulfur dioxide gas (SO2). In the wet medium, corrosion can occur uniformly or locally. Thereby, if in the effort of corrosion prevention done through the use of corrosion inhibitor (Muhammad Abduh, 2011).

2.5. Types of Corrosion

There are several types of corrosion due to its chemical reaction.

2.5.1. Uniform Corrosion

This is usually characterized by chemical or electrochemical reactions occurring on the reacting surface. The metal become thin and eventually there is a failure on the metal. Evenly corrosion is a very big deterioration of the material. However, this corrosion is bad observed because the age of the equipment can be accurately estimated with other simpler tests as shown in Figure 2.5.

Figure 2. 5 Uniform Corrosion

(International, n.d.)

2.5.2. Galvanic Corrosion

Potential differences usually occur between two different metals, when both are dipped into a corrosive solution. When the metal is in contact, the potential difference will result in the flow of electrons. Electrons flow from less noble (anodic) metals to more noble (cathodic) metals. As a result, less noble metal turns into positive ions because of the loss of electrons. The metal-positive ions react with negative ions in the electrolyte to a metal salt. Because of these events the anode surface loses metal.

Corrosion will attack metals with less corrosion resistance and less corrosion-resistant metal attacks. The corrosive metal will become the anode and the metal that is more resistant to corrosion attacks will be the cathode. Usually cathodic metals will be attacked slightly even without corrosion when the two metals are connected. This type of corrosion is called galvanic corrosion. An example of galvanic corrosion can be seen in the case of the battery stone in Figure 2.6. the carbon electrode as a precious metal or that is resistant to corrosion of the cathode and zinc as an anode with rust.

Figure 2. 6 Galvanic Corrosion (Services, n.d.)

2.5.3. Crevice Corrosion

It is a form of corrosion where corrosion occurs when there is a gap due to merging or unification of two equal metals having different oxygen levels with the outer area. This type of corrosion is usually caused by small holes, and cracks beneath the heads of bolts and rivets as shown in Figure 2.7.

Figure 2. 7 Crevice Corrosion (Lyon, n.d.)

2.5.4. Pitting Corrosion

Corrosion of wells is a very local form of corrosion attack (attacking on a particular area only) resulting in a hole in the metal. This hole may have a small or large diameter, but in many cases the hole is relatively small. The hole is isolated or sometimes looks like a rough surface. Pits can generally be described as cavities or holes with a surface diameter of approximately equal or less than the depth.

Corrosion of wells is one of the most damaging and dangerous forms of corrosion. It causes the equipment to fail because with a slight decrease in mass due to a hole, failure can occur easily. Often it is difficult to detect pits because of their small size and the holes are covered by corrosion as shown in Figure 2.8.

Figure 2. 8 Pitting Corrosion on Sink

(Consultants, n.d.)

2.5.5. Erosion Corrosion

Corrosion erosion is the acceleration of the degree of damage or attack on the metal due to the relative movement between corrosive liquids and metal surfaces. Generally, this movement is quite fast, and related to abrasion. The metals that are on the surface will turn into dissolved ions or become solid forms of corrosion products. Sometimes the influence of the environment can reduce the rate of corrosion, especially when local attacks occur in stagnant conditions, but this cannot be called erosion corrosion because the damage is not increased.

Physical form of erosion corrosion is characterized in appearance of grooves, trenches, waves, round holes, valleys, and usually indicates the direction pattern. Figure 2.9. shows the flow performance of erosion corrosion failure.

Figure 2. 9 Corrosion Erosion on Seawater Pipe (Bloging, n.d.)

2.5.6. Stress Corrosion

Mechanical forces such as tug or compression have very little effect on the metallization process on the same metallic part in terms of the milsace rate in mils per year. However, if it is a combination of tensile stress and a corrosive environment, then this condition is one of the main causes of material failure. This failure is a crack commonly called voltage corrosion.

This type of rust attack occurs very quickly, in minute size, for example if all the requirements for the occurrence of this strain (stress) strain have been met at a given moment of internal strain and the creation of corrosive conditions associated with corrosion and environmental temperature. Examples of stress corrosion on the pipe can be seen in Figure 2.10.

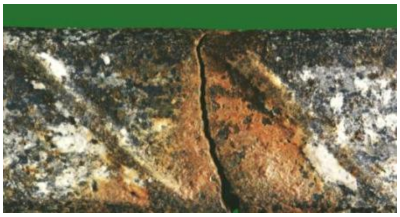

Figure 2. 10 Stress Corrosion (Hussaini, n.d.)

2.6. Corrosion Mechanism

The corrosion mechanism cannot be separated from the electrochemical reaction. Electrochemical reactions involve the displacement of electrons. Electron displacement is the result of a redox reaction (oxidation-reduction). The mechanism of corrosion through electrochemical reactions involves an anodic reaction. Anodic reactions (oxidation) are indicated by increased valence or electron product. The anodic reaction occurring in the metal corrosion process is:

$$M \rightarrow Mn+ + ne$$

In corrosion of metal M is the process of oxidation of the metal into one ion (n+) in the electron n release. The price of n depends on the nature of the metal as an example of iron:

$$Fe \rightarrow Fe2+ + 2e$$

The cathodic reaction also takes place in the corrosion process. The cathodic reaction indicated by decreasing the valence value or consumption of electrons resulting from the anodic reaction. The cathodic reaction in which oxygen from the air dissolves in an open solution. According to Haryono (2010) the corrosion mechanism that occurs in iron (Fe) is written as follows:

$$Fe(s) + H2O(l) + ½ O2(g) \rightarrow Fe(OH)2(s)$$

Fero hydroxide [Fe (OH) 2] is a temporary result which can be oxidized naturally by water and air to ferric hydroxide [Fe (OH) 3], so that the next reaction mechanism is:

$$4 Fe(OH)2(s) + O2(g) + 2H2O(l) \rightarrow 4Fe(OH)3(s)$$

The hydroxide ferries that are formed will turn into a brownish-browned Fe2O3 which we usually call rust. According to Vogel (1979) Reactions are:

$$2Fe(OH)3 \rightarrow Fe2O3+ 3H2O$$

In general, the corrosion mechanism occurring in a solution starts from the oxidized metal in the solution and releases the electrons to form positively charged metal ions. The solution will act as a cathode with a common reaction is the release of H2 and reduction of O2, due to reduced H + and H2O ions. This reaction occurs on the surface of the metal which will cause exfoliation due to dissolving the metal into the solution repeatedly. Figure 2.8. shows the corrosion mechanism on the metal surface.

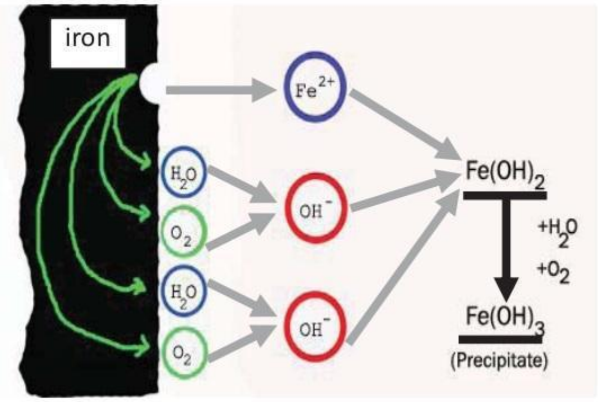

Figure 2. 11 Corrosion Mechanism (haryono, 2010)

2.7. Corrosion Rate

Corrosion is an electrochemical reaction, all of which affect the speed of a chemical reaction or the amount of current flowing will affect the rate of corrosion. Ohm's law can be applied to the electrical part of corrosion cells. The corrosion rate is directly proportional to the amount of current flowing in the electrochemical corrosion cells. If the current can be measured, a precise calculation of metal loss can be determined. This means that a measurement in amperes or milliamperes is calculated in weight loss per year. An Amp year is an Ampere that flows over a period of one year. Different metals have different corrosion rates. Conversion rate of corrosion of other unity:

1 mpy = 1000 ipy

1 mpy = 0.0254 mm/year

1 mpy = 25.4 µm/year

1 mpy = 12,100 in/month

1 mpy = 2.90 nm/hour

1 mpy = 0.0694 d gr/m2 year

Table 2. 1 Relative Corrosion Resistance (Narayan, 1983)

Relative Corrosion Resistance	Approximate Metric Equivalent				
	mpy	mm/year	µm/year	nm/year	pm/sec
Outstanding	< 1	< 0,02	< 25	< 2	< 1
Excellent	1-5	0,02-0,1	25-100	2-10	1-5
Good	20-50	0,1-0,5	100-500	10-50	5-20
Fair	20-50	0,5-1	500-1000	50-100	20-50
Poor	50-200	1,25-5	1000-5000	150-500	50-200
Unacceptable	200+	5+	5000+	500+	200+

2.7.1. Electrochemical Method

The electrochemical method is a method of measuring the corrosion rate by measuring the potential difference of the object to obtain the corrosion rate occurred, this method measures the corrosion rate at the time of measurement only which estimates the rate for a long time (estimating that although the results that occur between one time and another are different). The advantage of this method is we can directly know the rate of corrosion at the time of measuring, until the measurement time does not take a long time. The disadvantage of this method is that it cannot accurately describe the corrosion rate because it can only measure the corrosion rate only at certain times, until the usage life or the conditions to be tested.

This electrochemical method using the formula based on Faraday's Law is using the following formula:

$$\text{CR (mmpy)} = K\ \frac{a\ x\ i}{n\ x\ D}\ \text{mmpy}$$

Where:

CR = Corrosion rate

K = Constant factor, mpy = 0,129 ; µm/yr = 3,27 ; mm/yr = 0,00327

a = Atomic weight of metal

i = Current density (µA/cm2)

n = Number of electron lost

D = Density (g/cm3)

2.7.2. Three-Electrode Cells

The three-electrode cell is a standard laboratory device for quantitative research on the corrosion properties of materials that constitute the perfection of wet corrosion cells (Tretheway, 1991), the three-electrode cells include:

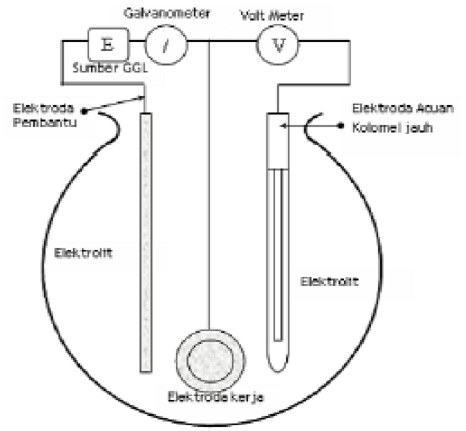

Figure 2. 12 Three-electrode Cells

(Sutrisna, 2008)

2.8. ASTM (American Society for Testing and Material)

ASTM International is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. Some 12.575 ASTM voluntary consensus standards operate globally. Founded in 1898 as the American Section of the International Association for Testing Materials.

ASTM G102-89 is a standard practice for calculation of corrosion rates and related information from electrochemical. It is intended to provide guidance in converting the results of electrochemical measurements to rates of uniform corrosion. Calculation methods for converting corrosion current density values to either mass loss rates or average penetration rates are given for most engineering alloys. In addition, some guidelines for converting polarization resistance values to corrosion rates are provided. And there are many standard ASTM used, for the preparation until the finishing specimen using the ASTM G1-90, for the soaking the specimen into a corrosive solution using the ASTM G31-72.

2.8.1. ASTM G1-90 (Standard Practice for Preparing, Cleaning, and Evaluation Corrosion Test Specimens):

This practice covers suggested procedures for preparing bare, solid metal specimens for tests, for removing corrosion products after the test has been completed, and for evaluating the corrosion damage that has occurred. Emphasis is placed on procedures related to the evaluation of corrosion by mass loss and pitting measurements.

2.8.2. ASTM G31-72 (Standard Practice for Laboratory Immersion Corrosion Testing of Materials):

This practice describes accepted procedures for and factors that influence laboratory immersion corrosion tests, particularly mass loss tests. These factors include specimen preparation, apparatus, test conditions, methods of cleaning specimens, evaluation of results, and calculation and reporting of corrosion rates. This practice also emphasizes the importance of recording all pertinent data and provides a checklist for reporting test data.

2.9. Standard DNV GL

2.9.1. DNV GL 20 Corrosion Protection of Ships: 2000

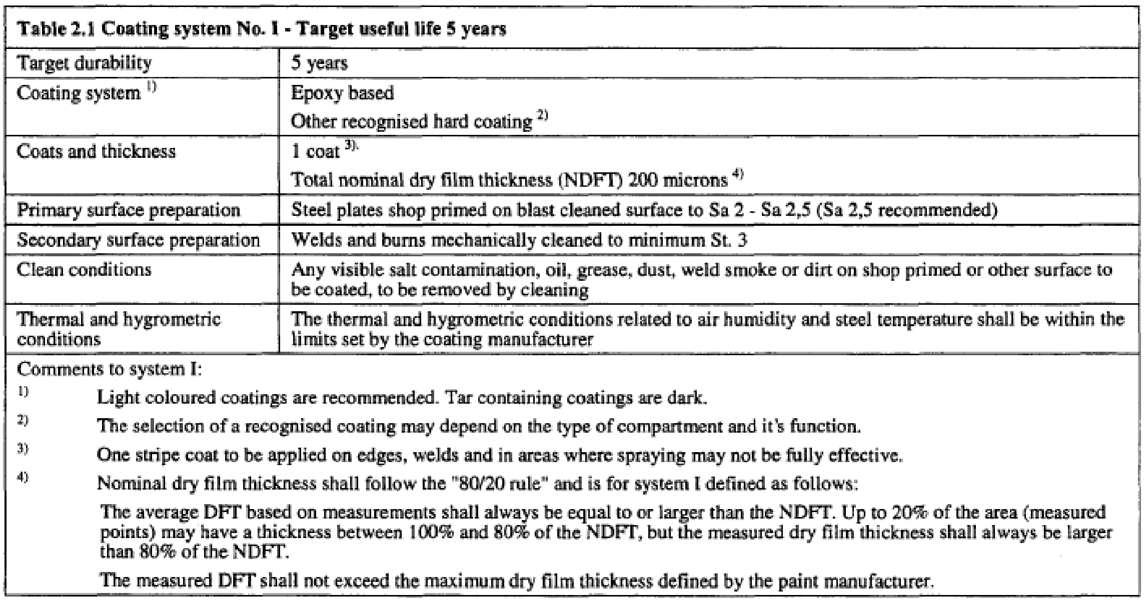

Table 2.1 Coating system No. 1 - Target useful life 5 years

Target durability	5 years
Coating system 1)	Epoxy based Other recognised hard coating 2)
Coats and thickness	1 coat 3). Total nominal dry film thickness (NDFT) 200 microns 4)
Primary surface preparation	Steel plates shop primed on blast cleaned surface to Sa 2 - Sa 2,5 (Sa 2,5 recommended)
Secondary surface preparation	Welds and burns mechanically cleaned to minimum St. 3
Clean conditions	Any visible salt contamination, oil, grease, dust, weld smoke or dirt on shop primed or other surface to be coated, to be removed by cleaning
Thermal and hygrometric conditions	The thermal and hygrometric conditions related to air humidity and steel temperature shall be within the limits set by the coating manufacturer

Comments to system I:

1) Light coloured coatings are recommended. Tar containing coatings are dark.

2) The selection of a recognised coating may depend on the type of compartment and it's function.

3) One stripe coat to be applied on edges, welds and in areas where spraying may not be fully effective.

4) Nominal dry film thickness shall follow the "80/20 rule" and is for system I defined as follows:

The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 20% of the area (measured points) may have a thickness between 100% and 80% of the NDFT, but the measured dry film thickness shall always be larger than 80% of the NDFT.

The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer.

Figure 2. 13 DNV GL 20 Corrosion Protection of Ships (GL, 2000)

This is a standard of DNV GL 20 about Corrosion Protection of Ships. This standard shows that protection using epoxy is allowed, the target lifetime of the operation for 5 years. The experiment will be applied as the standard for target of 5 years, which is the thickness is 200 µ and there is 1 layer for the coating.

2.9.2. DNV GL Part 4 Chapter 6: 2011

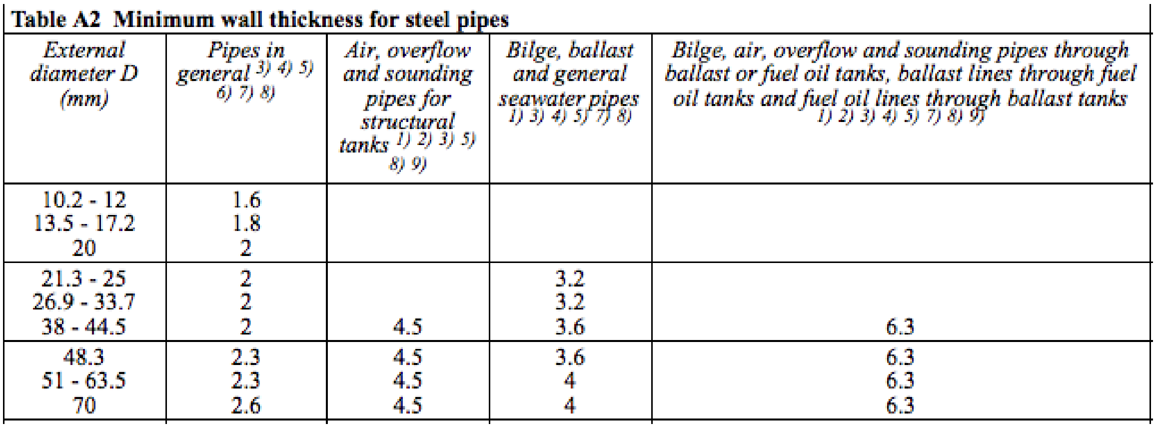

Table A2 Minimum wall thickness for steel pipes

External diameter D (mm)	*Pipes in general* 3) 4) 5) 6) 7) 8)	*Air, overflow and sounding pipes for structural tanks* 1) 2) 3) 5) 8) 9)	*Bilge, ballast and general seawater pipes* 1) 3) 4) 5) 7) 8)	*Bilge, air, overflow and sounding pipes through ballast or fuel oil tanks, ballast lines through fuel oil tanks and fuel oil lines through ballast tanks* 1) 2) 3) 4) 5) 7) 8) 9)
10.2 - 12	1.6			
13.5 - 17.2	1.8			
20	2			
21.3 - 25	2		3.2	
26.9 - 33.7	2		3.2	
38 - 44.5	2	4.5	3.6	6.3
48.3	2.3	4.5	3.6	6.3
51 - 63.5	2.3	4.5	4	6.3
70	2.6	4.5	4	6.3

Figure 2. 14 DNV GL Part 4 Corrosion Protection of Ships (GL, 2011)

The specimen of the experiment used steel carbon pipe Schedule 40 with diameter of 2 inch or equivalent with 50.8 mm. The standard shows the minimum wall thickness for steel pipe for diameter 48.3 – 51 mm is 3.6 mm.

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CHAPTER III
METHODOLOGY

3.1. General

The method of research conducted in this case is the experimental method of 3 types of pipes (carbon steel pipe, carbon steel pipe with epoxy coating, and galvanized carbon steel pipe). For testing the corrosion rate on the pipe will be provided with aquadest and NaCl contain with salinity 35%. Variations of pipe immersion every 72 hours will be observed the corrosion rate that occurs, and the maximum immersion time is 144 hours or equivalent to 6 days. After the result of corrosion rate at each variation of immersion time will be depicted on the graph to know the difference of corrosion rate result.

3.2. Methodology Flowchart

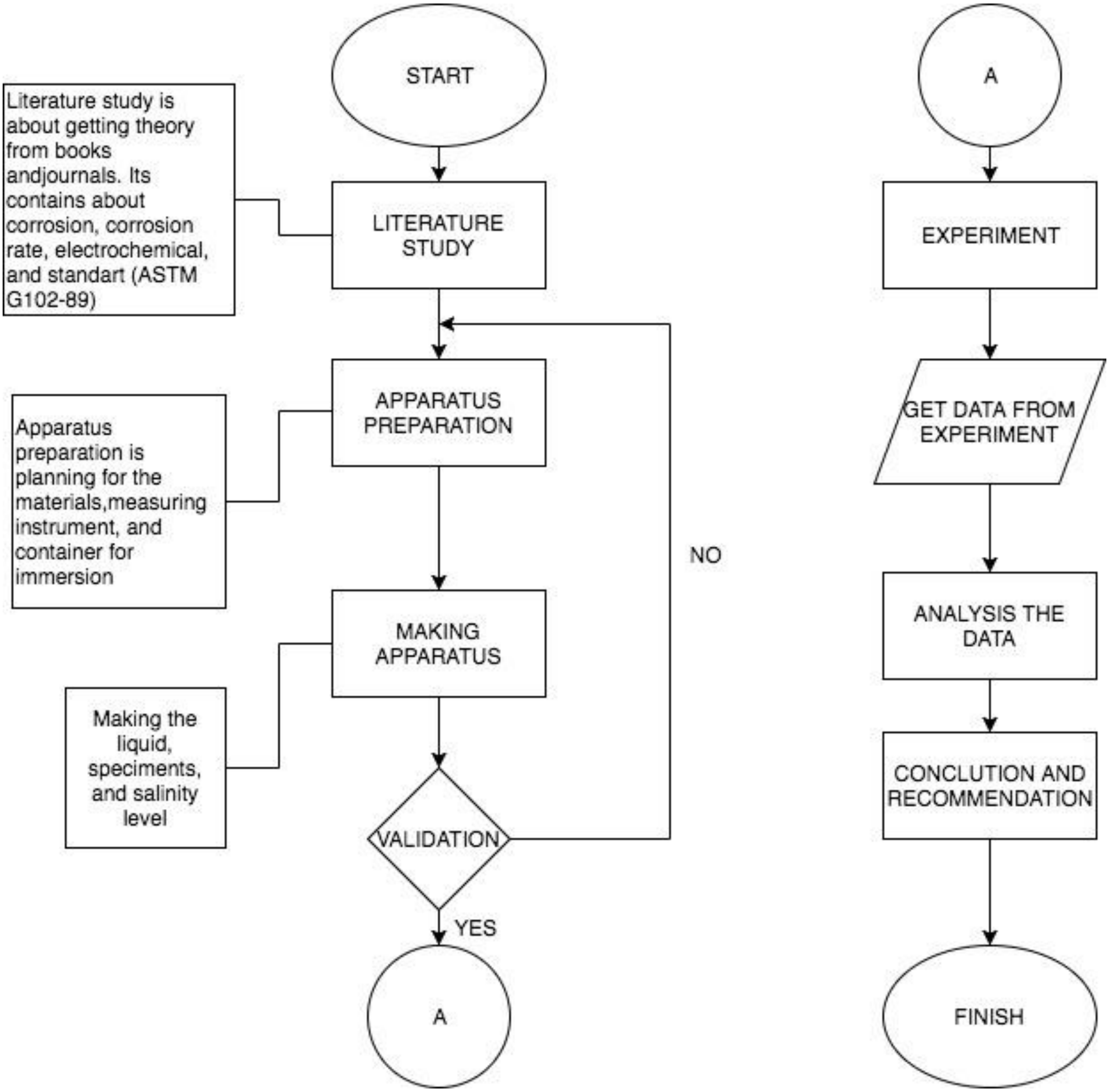

Figure 3. 1 Methodology Flowchart

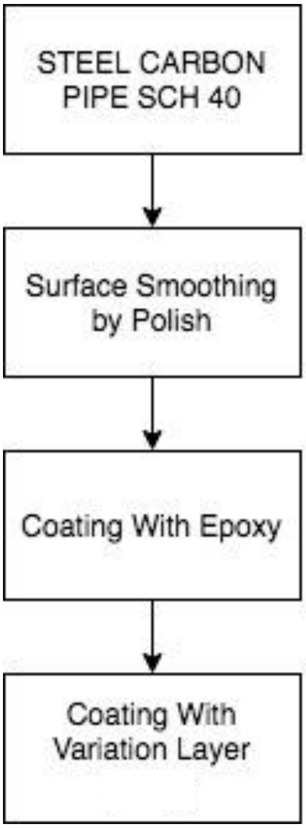

Figure 3. 3 Making Pipe with Epoxy Coating

Figure 3. 4 Making Pipe with Galvanize Coating

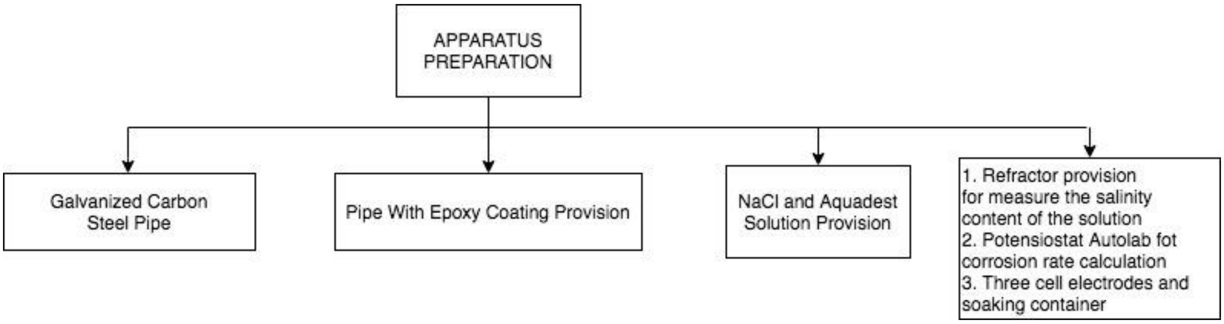

Figure 3. 2 Apparatus Preparation Flowchart

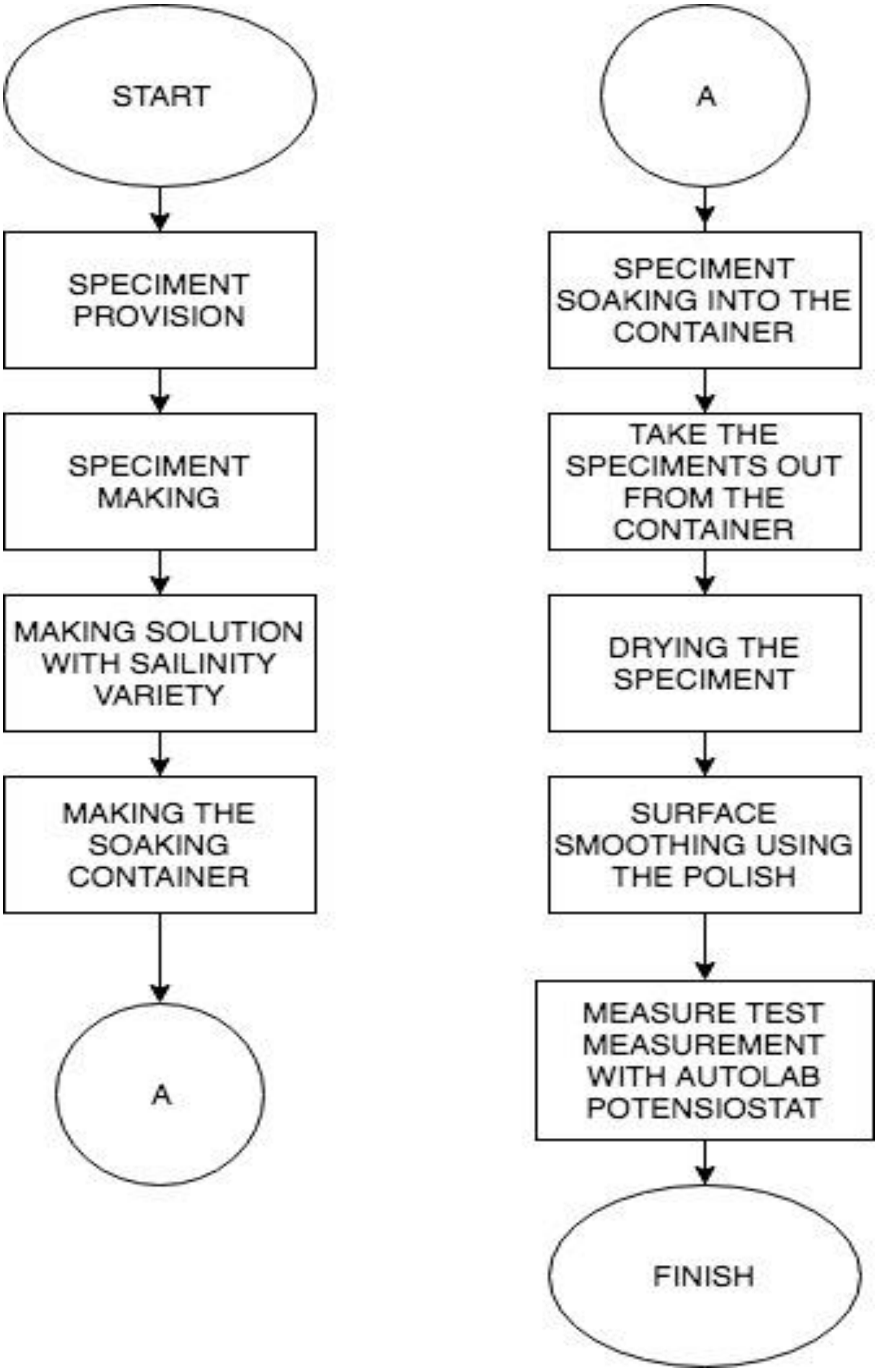

Figure 3. 5 Experiment Flowchart

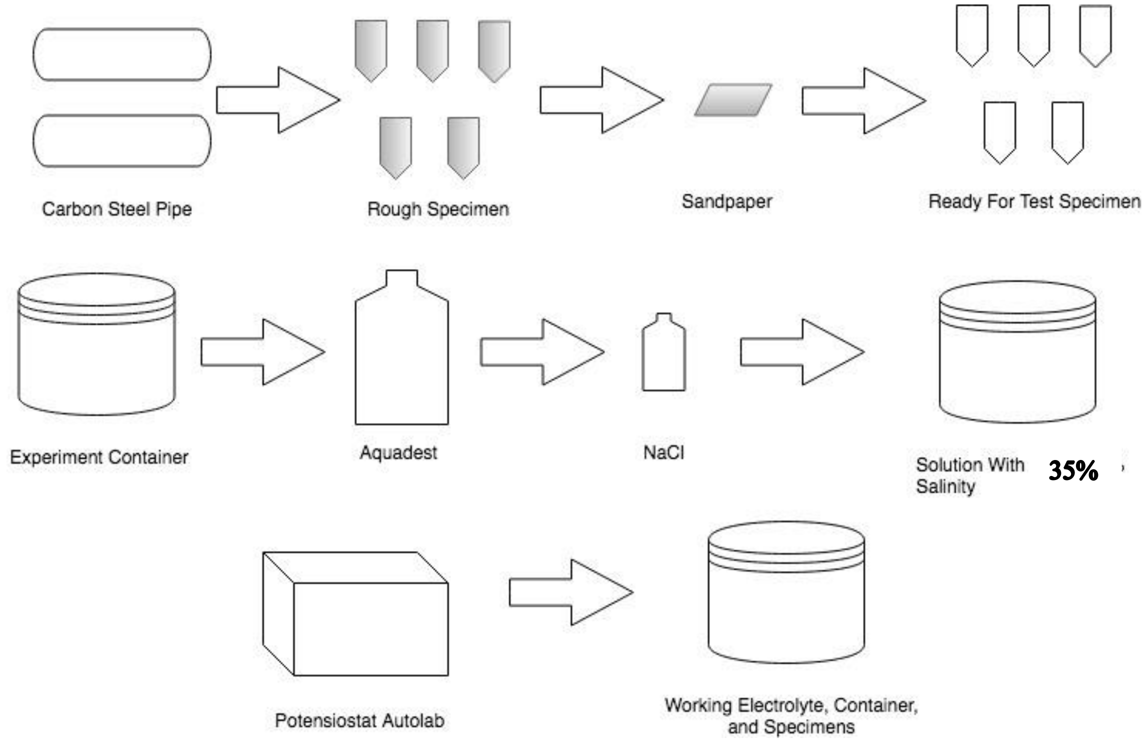

Figure 3. 7 Test Specimen Flowchart

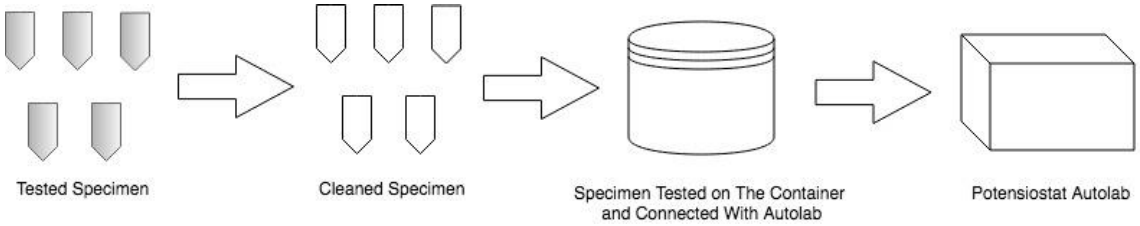

Figure 3. 6 Test Specimen with Potensiostat Autolab PGSTAT128N and NOVA software Flowchart

3.3. Bachelor Thesis Methodology

The methodology used in conducting the bachelor thesis process will be explained as following.

3.3.1. Problem Identification

This step of methodology is the first thing for the author must know, which is why the problem exist and the author must look for the problems. The purpose of this activity is to simplify the problems so that the author can conduct the bachelor thesis in accordance with the author want to do.

3.3.2. Literatures Study

Literature study means the sources that the author taken from, or it is commonly said references. In compiling this bachelor thesis, the author needs some references or literatures. These are the literatures are obtained from:

- Corrosion.
- Corrosion rate.
- Electrochemical.

3.3.3. Apparatus Preparation

On this step there are some things that need for provision before doing the experiment. There are some tools and materials needed, there are:

- Potensiostat Autolab PGSTAT128N.
- NOVA software for corrosion rate measurement.
- Grinder.
- Sandpaper 1000 grade.
- Carbon steel pipe Schedule 40.
- Pipe with epoxy coating.
- Galvanized carbon steel pipe.
- Soaking container.
- Solution with 35% solution.

This step also needed for calibration and validation to make sure the data will be obtained as desired for the result. Calibration performed on the corrosion rate measurement. For calibration and validation step, the author will be decided if the system designed appropriate or not. If the system designed appropriate, the next step is continuing to the making apparatus. But if the system is not appropriate, the step will be back to the apparatus preparation until the system desired appropriate.

3.3.4. Making Apparatus

In this step the provision of all equipment to the implementation of corrosion rate on the specimens provided. Required tools and materials are potensiostat autolab PGSTAT128N and NOVA software corrosion rate measurement instrument, grinding wheel, sand paper, carbon steel pipe, pipe with epoxy coating, galvanized carbon steel pipe, immersion container, solution with salinity 35%.

3.3.5. Experiment and Data Collection

This step is the immersion of the specimens on the soaking container with the 35% salinity. The immersion time also has the different variety from 72 hours until 144 hours. After that, the specimens will be calculated on the potensiostat autolab PGSTAT128N and get the data from NOVA software.

3.3.6. Corrosion Rate Calculation

Every 72 hours, the specimens will be recorded and calculated to know the corrosion rate, this step will be continued until reach 144 hours. The device used for calculation is potensiostat autolab PGSTAT128N, which is connected to the NOVA software.

3.3.7. Data Process and Analyzing

After 144 hours immersion done, this step will be analyzed for the corrosion rate for each specimen. The data obtained will be compared by graph, relationship of corrosion rate values that occur with salinity, and time of immersion.

3.3.8. Conclusion and Recommendation

After all the step done, the final step is get the conclusions of analysis and experiment. A great hope of the conclusion is answer for the problem that became the purpose of this thesis. Therefore, there are also needed suggestions based on the results of research in order to make this thesis get on point.

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CHAPTER IV
ANALYSIS AND DISCUSSION

Table 4. 1 Carbon Steel Pipe Chemical Composition Specimen

4.1. Carbon Steel Chemical Composition Specimen

On this thesis, the raw material will be made into several specimens. Each specimen will be treated to be carbon steel, galvanized, and coating with epoxy:

- Steel Carbon Composition and Characteristic (PT. Benteng Anugerah Sejahtera):

1) Material : Steel Carbon.
2) Diameter : 2 inch.
3) Length : 6 meter.

- Specimen:

1) Length : 10 mm.
2) Width : 10 mm.
3) Thickness : 4 mm.
4) Sandpaper : Abrasive sandpaper 1000 grade wet dry proof.
5) Aquadest : PH 5,5-7,0 (SNI).
6) NaCl : Density 2,16 g/cm3, melting point: 801 oC, boiling point: 1465 oC, solubility in water: 25 oC.
7) Epoxy : International INTERTUF 262 (KHA303).

C	Si	Mn	S	P	Cr	Ni	Cu
0.21	0.24	0.54	0.02	0.02	0.04	0.02	0.02

4.2. Making Apparatus

Before doing corrosion rate analysis experiment, there are several things need to prepare. There are carbon steel pipe, galvanic solution, epoxy, potensiostat autolab PGSTAT128N, sandpaper, grinding machine, soaking container, and solution with different salinity.

4.2.1. Carbon Steel Pipe Specimen

At the beginning the pipe length is 6 meter with diameter 2 inch schedule 40. On this experiment grinding machine is needed to cut the carbon steel into 3 pieces with dimension:

Length : 10 mm
Width : 10 mm
Thickness : 4 mm

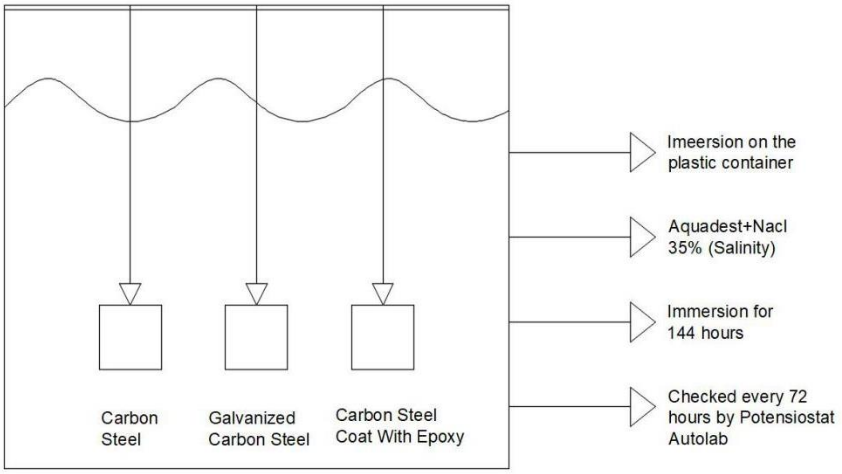


Figure 4. 2 Specimen in Immersion

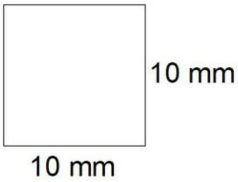


Figure 4. 3 Specimen Dimension

Figure 4. 1 Rough Specimen

Before Cut

For the experiment using the potensiostat autolab PGSTAT128N and get the data from NOVA software, the specimen will be cut again for the measurement of the tools.

4.2.2. Polishing Specimen

After the carbon steel pipe cut with the desire dimension, sandpaper needed to polish the surface of the carbon steel pipe with abrasive sandpaper 1000 grade wet dry proof.

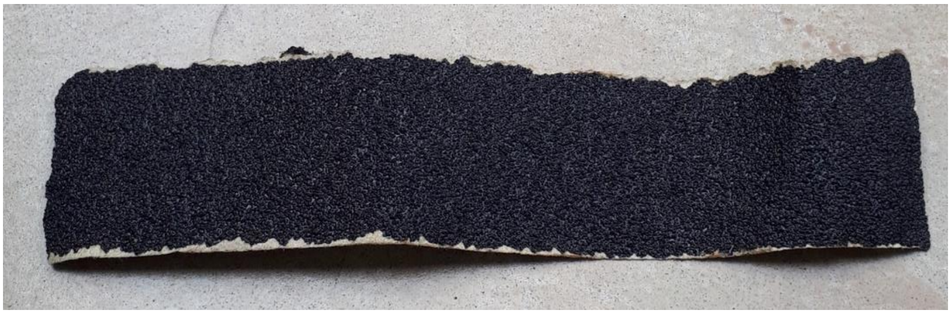


Figure 4. 4 Sandpaper 1000 Grade

Figure 4. 5 Polished Specimen

Figure 4. 6 Polishing Specimen Using Grinder

4.2.3. Soaking the Specimen

There are several things to prepare during this step:

4.2.3.1 Tools and Materials

1) Soaking Specimen and Solution

This tool serves as a predefined salinity container as the standard of ASTM G31-72.

2) Aquadest

For making the, aquadest serves as a NaCl solvent.

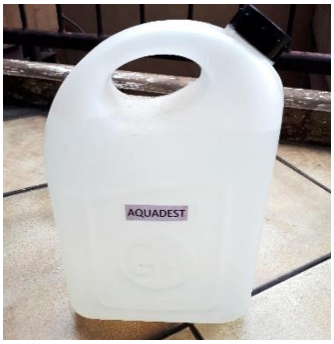


Figure 4. 7 Aquadest

3) NaCl

NaCl with amount 35 gram serves as diluted for salinity making of 1 liter aquadest.

Figure 4. 8 NaCL

4) Epoxy

The international INTERTUF 262 with red color with code KHA303 epoxy used to coat the carbon steel pipe with 250 μ.

Figure 4. 9 International INTERTUF 262 Epoxy

5) Salinity 35%

For making this salinity, NaCl needed to dissolved into the aquadest. The ratio of the NaCl is 35 gram and 1 liter of aquadest make the salinity into 35%. To know the salinity is using the salt meter.

6) Soak the Specimen

After the desired specimen cut, the next step is soak the specimen into the container which has been filled by the salinity solution of 35%. The container is filled by 3 specimens. The immersion time is 144 hours (6 days) and every 72 hours (3 days) will be checked to the potensiostat autolab PGSTAT128N and NOVA software.

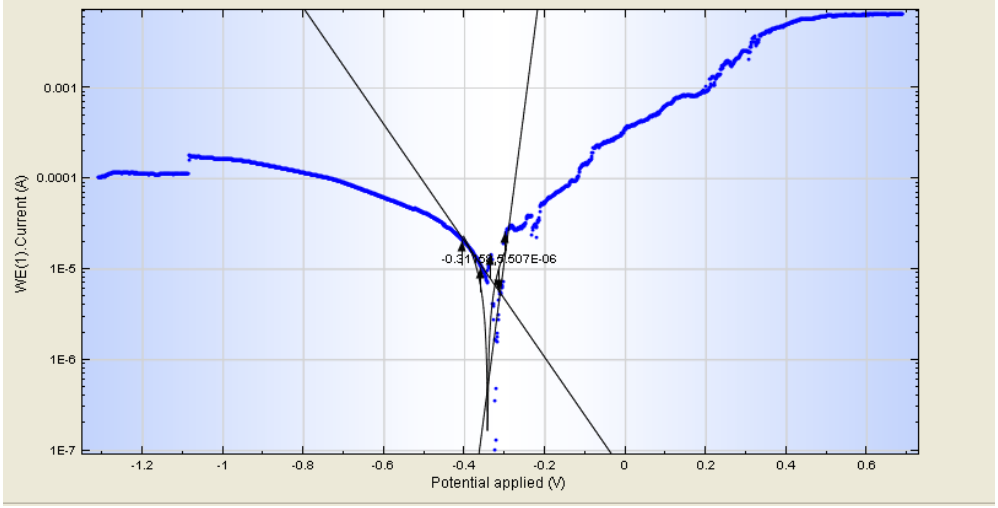
Table 4. 2 Time Table Immersion Specimen

Time Table Immersion Specimen				
No.	Date	Day	Time Immersion	Photo
1	25 – 05 – 2018 - 28 – 05 – 2018	Friday - Monday	09.00 - 09.00	
2	28 – 05 – 2018 - 31 – 05 – 2018	Monday - Thursday	23.10 – 23.10	

4.3. Corrosion Rate Calculation

After corrosion rate calculation using Potensiostat Autolab PGSTAT128N and NOVA software done, the result of the calculation will be obtained. There are current density, pontential, and corrosion rate. Aside from the data obtained, there is also graphic form the Potensiostat Autolab PGSTAT128N and NOVA software that shown the current density and potential. The x-axis from tafel graphic refers as volt and already specified before experiment, the y-axis refers current density. Current density from the experiment can be change but the volt remains the same.

4.3.1. Experiment Result on Specimen A (Carbon Steel Pipe) For 72 Hours



Graphic 4. 1 Result Specimen A (Carbon Steel Pipe) For 72 Hours

This graphic shown that corrosion rate specimen A (carbon steel pipe) with immersion for 72 hours done by potensiostat autolab PGSTAT128N and get the data from NOVA software. After the software process the corrosion rate data, the graphic shows dashed line and connected the intersection with high precision. From the result of the intersection, the current density is known from the potential. The result of the experiment is:.

Table 4. 3 Specimen A (Carbon Steel Pipe) For 72 Hours Result

Corrosion Rate (mmpy)	Potential (mV)	Current Density (μA/cm^2)
0.19478	-342.87	16.763

From the table below, result obtained of the corrosion rate, potential, and current density result of specimen A after test. The corrosion rate is 0.19478 mmpy, potential is

-342.87 mV, and the current density is 16.763 µA/cm2. And the calculation using the Faraday Law with electrochemical method for specimen A with immersion for 72 hours:

K = 0.00327

a = 27.925 g/mol

i = 16.763 µA/cm2

n = 1

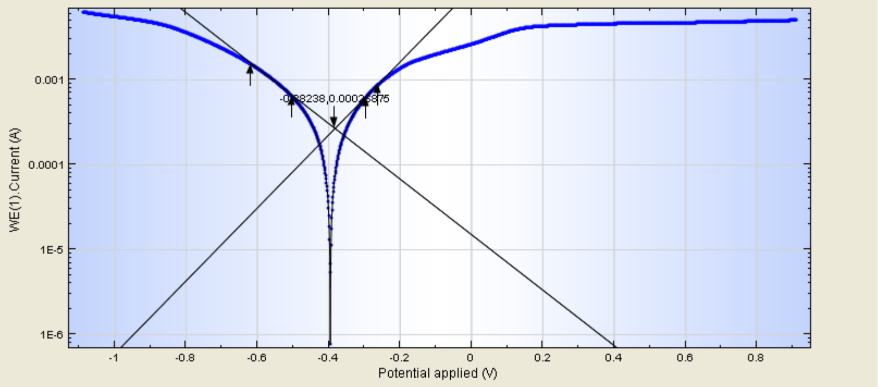
D = 7.86 g/cm3

CR (mmpy) = K ai/nD

CR (mmpy) = 0.00327 x 27.925 x 16.763 / 7.86

CR (mmpy) = 0.194746712 mmpy

4.3.2. Experiment Result on Specimen B (Carbon Steel Pipe Coated with Epoxy) For 72 Hours



Graphic 4. 2 Result Specimen B (Carbon Steel Pipe Coated With Epoxy) For 72 Hours

This graphic shown that corrosion rate specimen B (carbon steel pipe coated with epoxy) with immersion for 72 hours done by potensiostat autolab PGSTAT128N and get the data from NOVA software. After the software process the corrosion rate data, the graphic shows dashed line and connected the intersection with high precision. From the result of the intersection, the current density is known from the potential. The result of the experiment is:

Table 4. 4 Specimen B (Carbon Steel Pipe Coated with Epoxy) For 72 Hours

Corrosion Rate (mmpy)	Potential (mV)	Current Density (µA/cm2)
0.01842	-382.38	1.5837

From the table below, result obtained of the corrosion rate, potential, and current density result of specimen B after test. The corrosion rate is 0.01842 mmpy, potential is -352.84 mV, and the current density is 1.5837 µA/cm2. And the calculation using the Faraday Law with electrochemical method for specimen B with immersion for 72 hours:

K = 0.00327

a = 27.925 g/mol

i = 1.5837 µA/cm2

n = 1

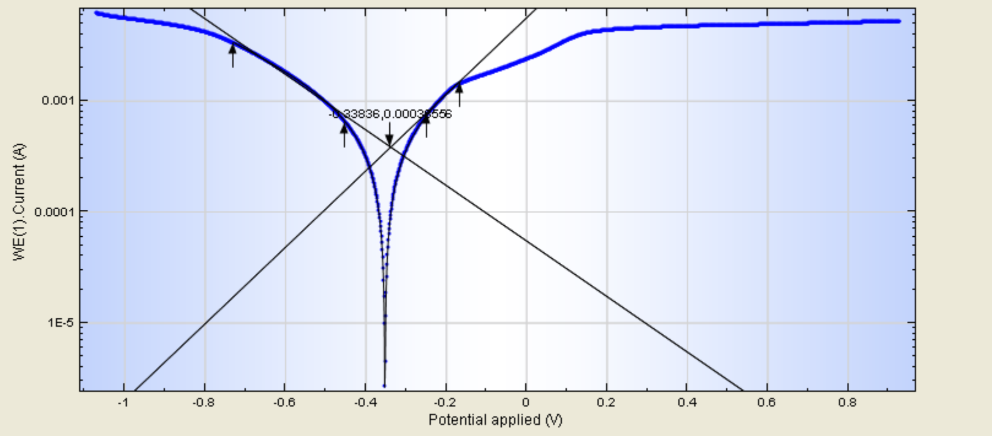
D = 7.86 g/cm3

CR (mmpy) = K ai/nD

CR (mmpy) = 0.00327 x 27.925 x 1.5837 / 7.86

CR (mmpy) = 0.018398877 mmpy

4.3.3. Experiment Result on Specimen C (Galvanized Carbon Steel Pipe) For 72 Hours



Graphic 4. 3 Result Specimen C (Galvanized Carbon Steel Pipe) For 72 Hours

This graphic shown that corrosion rate specimen C (galvanized carbon steel pipe) with immersion for 72 hours done by potensiostat autolab PGSTAT128N and get the data from NOVA software. After the software process the corrosion rate data, the graphic shows dashed line and connected the intersection with high precision. From the result of the intersection, the current density is known from the potentioal. The result of the experiment is:

Table 4. 5 Specimen C (Galvanized Carbon Steel Pipe) For 72 Hours

Corrosion Rate (mmpy)	Potential (mV)	Current Density (µA/cm2)
0.001825	-352.84	0.15712

From the table below, result obtained of the corrosion rate, potential, and current density result of specimen C after test. The corrosion rate is 0.001825 mmpy, potential is -352.84 mV, and the current density is 0.15712 µA/cm2. And the calculation using the Faraday Law with electrochemical method for specimen C with immersion for 72 hours:

K = 0.00327

a = 27.925 g/mol

i = 0.15712 µA/cm2

n = 1

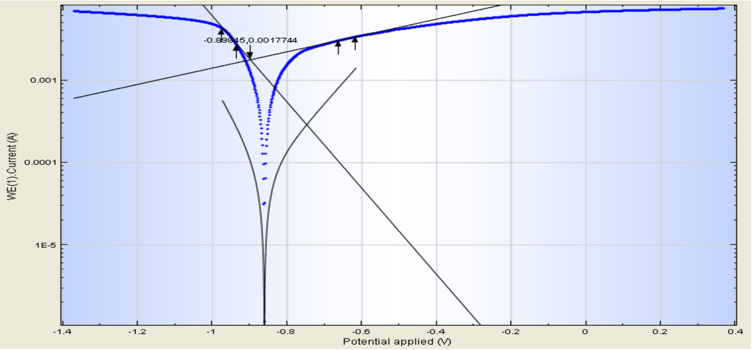
D = 7.86 g/cm3

CR (mmpy) = K ai/nD

CR (mmpy) = 0.00327 x 27.925 x 0.15712 / 7.86

CR (mmpy) = 0.001825366 mmpy

4.3.4. Experiment Result on Specimen A (Carbon Steel Pipe) For 144 Hours



Graphic 4. 4 Result Specimen A (Carbon Steel Pipe) For 144 Hours

This graphic shown that corrosion rate specimen A (carbon steel pipe) with immersion for 144 hours done by potensiostat autolab PGSTAT128N and get the data from NOVA software. After the software process the corrosion rate data, the graphic shows dashed line and connected the intersection with high precision. From the result of the intersection, the current density is known from the potential. The result of the experiment is:

Table 4. 6 Specimen A (Carbon Steel Pipe) For 144 Hours

Corrosion Rate (mmpy)	Potential (mV)	Current Density (µA/cm2)
0.28618	-861.24	1.5837

From the table below, result obtained of the corrosion rate, potential, and current density result of specimen A after test. The corrosion rate is 0.28618 mmpy, potential is -861.24 mV, and the current density is 24.628 µA/cm2. And the calculation using the Faraday Law with electrochemical method for specimen A with immersion for 144 hours:

K = 0.00327

a = 24.628 g/mol

i = 1.5837 µA/cm2

n = 1

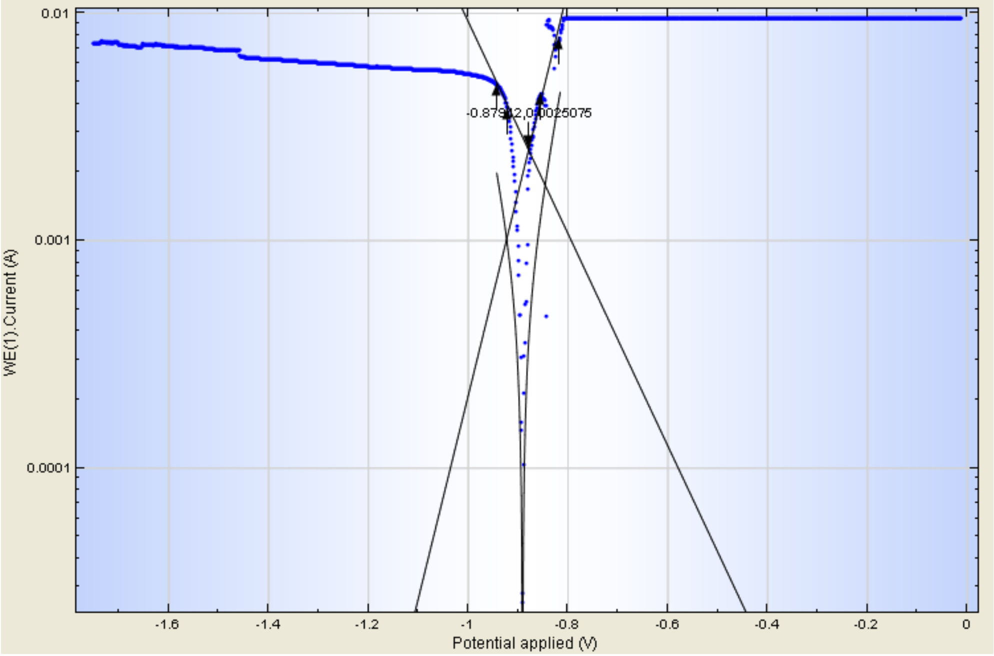
D = 7.86 g/cm3

CR (mmpy) = K ai/nD

CR (mmpy) = 0.00327 x 27.925 x 24.628 / 7.86

CR (mmpy) = 0.28611955 mmpy

4.3.5. Experiment Result on Specimen B (Carbon Steel Pipe Coated with Epoxy) For 144 Hours



Graphic 4. 5 Result Specimen B (Carbon Steel Pipe Coated With Epoxy) For 144 Hours

This graphic shown that corrosion rate specimen B (carbon steel pipe coated with epoxy) with immersion for 144 hours done by potensiostat autolab PGSTAT128N and get the data from NOVA software. After the software process the corrosion rate data, the graphic shows dashed line and connected the intersection with high precision. From the result of the intersection, the current density is known from the potential. The result of the experiment is:

Table 4. 7 Specimen B (Carbon Steel Pipe Coated with Epoxy) For 144 Hours

Corrosion Rate (mmpy)	Potential (mV)	Current Density (µA/cm2)
0.019033	-891.21	1.6383

From the table below, result obtained of the corrosion rate, potential, and current density result of specimen B after test. The corrosion rate is 0.019033 mmpy, potential is

-891.21 mV, and the current density is 1.6383 µA/cm2. And the calculation using the Faraday Law with electrochemical method for specimen B with immersion for 144 hours:

K = 0.00327

a = 27.925 g/mol

i = 1.6383 µA/cm2

n = 1

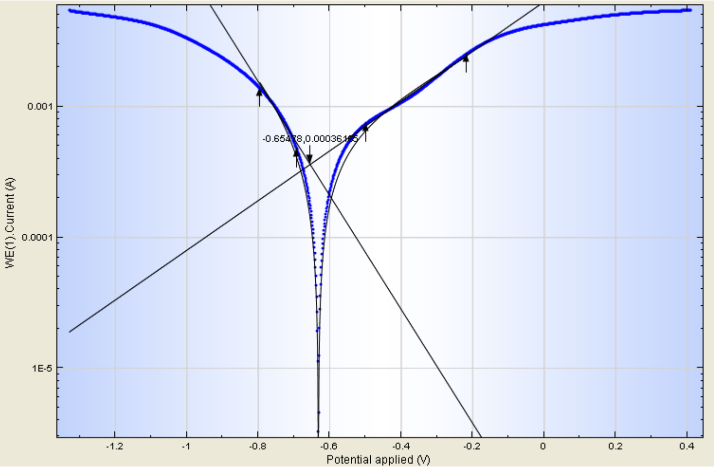
D = 7.86 g/cm3

CR (mmpy) = K ai/nD

CR (mmpy) = 0.00327 x 27.925 x 1.6383 / 7.86

CR (mmpy) = 0.0190332 mmpy

4.3.6. Experiment Result on Specimen C (Galvanized Carbon Steel Pipe) For 144 Hours



Graphic 4. 6 Result Specimen C (Galvanized Carbon Steel Pipe) For 144 Hours

This graphic shown that corrosion rate specimen C (galvanized carbon steel pipe) with immersion for 144 hours done by potensiostat autolab PGSTAT128N and get the data from NOVA software. After the software process the corrosion rate data, the graphic shows dashed line and connected the intersection with high precision. From the result of the intersection, the current density is known from the potential. The result of the experiment is:

Table 4. 8 Specimen C (Galvanized Carbon Steel Pipe) For 144 Hours

Corrosion Rate (mmpy)	Potential (mV)	Current Density (µA/cm2)
0.002634	-632.03	0.1697

From the table below, result obtained of the corrosion rate, potential, and current density result of specimen C after test. The corrosion rate is 0.002634 mmpy, potential is -632.03 mV, and the current density is 0.1697 µA/cm2. And the calculation using the Faraday Law with electrochemical method for specimen C with immersion for 144 hours:

K = 0.00327

a = 27.925 g/mol

i = 0.1697 µA/cm2

n = 1

D = 7.86 g/cm3

CR (mmpy) = K ai/nD

CR (mmpy) = 0.00327 x 27.925 x 0.1697 / 7.86

CR (mmpy) = 0.001971516 mmpy

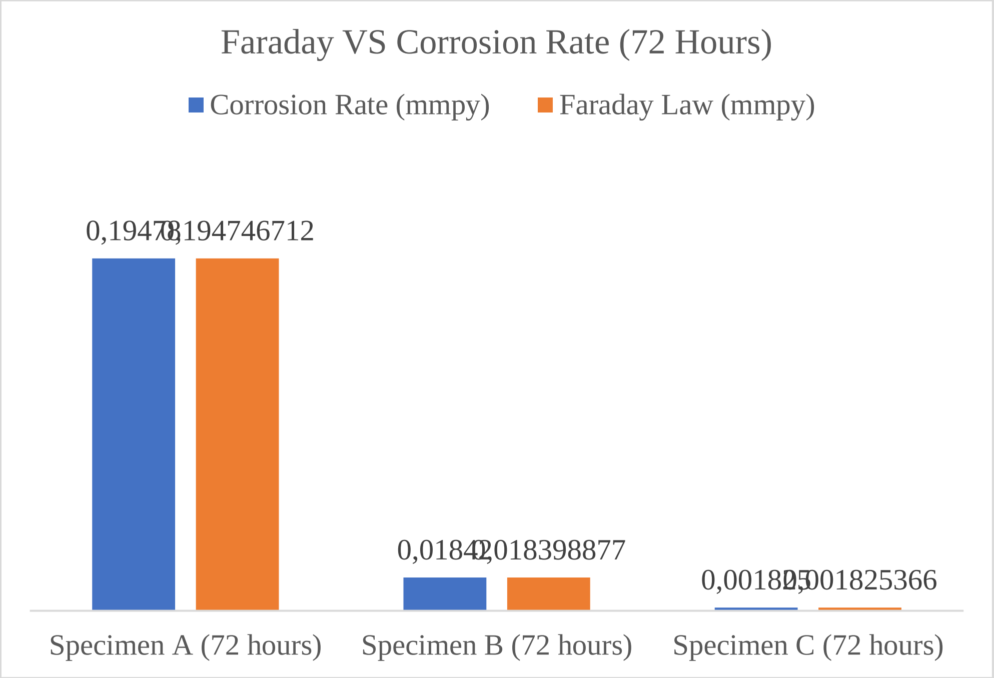
4.4. Comparison of Faraday Law Calculations

Table 4. 9 Comparison of Faraday Law Calculations

Corrosion Rate		Immersion Time (hours)	Specimen
NOVA (mmpy)	Faraday Law (mmpy)		
0.19478	0.194746712	72	Specimen A (72 hours)
0.01842	0.018398877	72	Specimen B (72 hours)
0.001825	0.001825366	72	Specimen C (72 hours)
0.28618	0.28611955	144	Specimen A (144 hours)
0.019033	0.0190332	144	Specimen B (144 hours)
0.002634	0.001971516	144	Specimen C (144 hours)

After the calculation done by the faraday law, the graphic comparison for each specimen can be obtained.

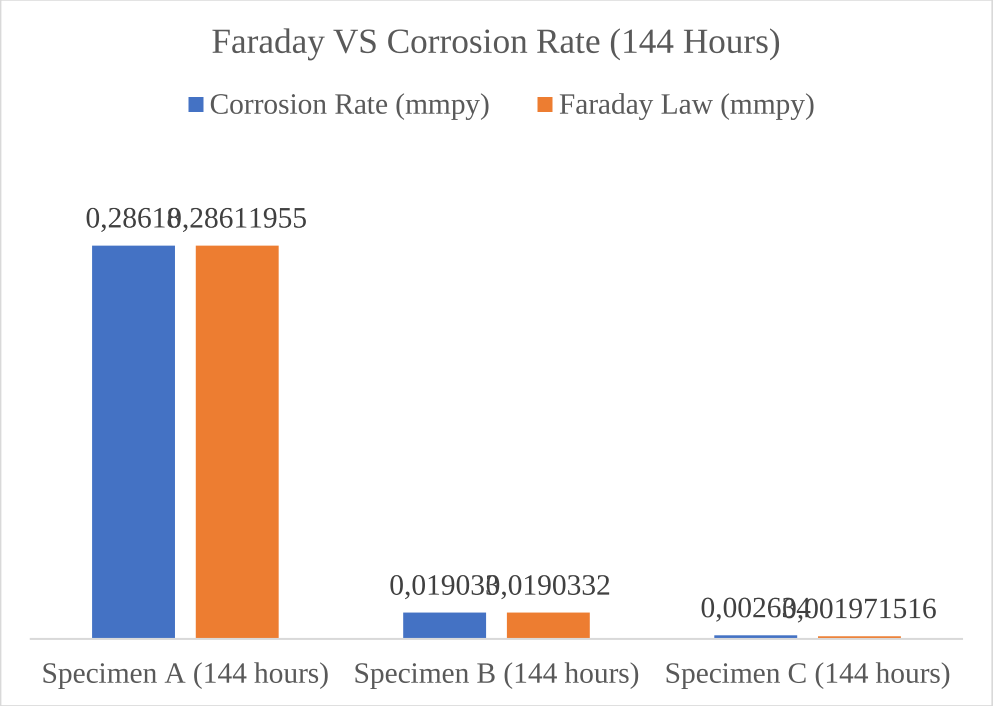
4.4.1. Comparison Corrosion Rate NOVA Software and Faraday Law for Immersion 72 Hours



Graphic 4. 7 Corrosion Rate and Faraday Law Comparison For 72 Hours Immersion

The graphic shows the difference calculation from NOVA software and faraday law immersion for 72 hours. The difference on specimen A (carbon steel pipe) result from the NOVA software is 0.19478 mmpy and the faraday law is 0.194746712 mmpy, the difference is 0.00003328. On specimen B (carbon steel pipe coated with epoxy) result from the NOVA software is 0.01842 mmpy and the faraday law is 0.018398877 mmpy, the difference is 0.000021123. On specimen C (galvanized carbon steel pipe) result from the NOVA software is 0.001825 mmpy and the faraday law is 0.001825366 mmpy, the difference is 0.000000366.

4.4.2. Comparison Corrosion Rate NOVA Software and Faraday Law for Immersion 144 Hours



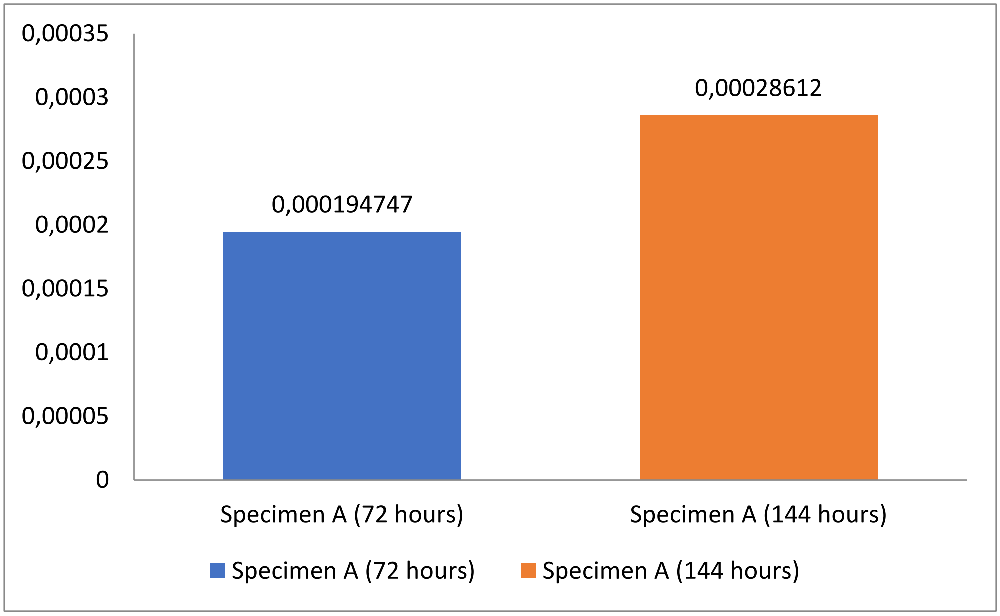
Graphic 4. 8 Comparison Specimen A for Immersion 72 Hours and 144 Hours

Specimen A is the carbon steel pipe with no protection or coating. The graphic shows the difference between immersion for 72 hours and 144 hours from the faraday law calculation. The result of 72 hours immersion shows the corrosion rate 0.19478 mmpy. For the result of 144 hours immersion shows the corrosion rate 0.28618 mmpy. The difference of the result is 0.0914 mmpy, the significant difference caused by specimen A did not coated for protection.

This specimen has the biggest corrosion rate. According to the standard of DNV GL Part 4 Chapter 6: 2011, the specimen of the experiment used steel carbon pipe Schedule 40 with diameter of 2 inch or equivalent with 50.8 mm. The standard shows the minimum wall thickness for steel pipe for diameter 48.3 – 51 mm is 3.6 mm. This specimen's lifetime is about ±33 months with corrosion rate 47.20973 mmpy.

4.5. Comparison Each Specimen

4.5.1. Comparison Specimen A



Graphic 4. 9 Comparison Specimen A for Immersion 72 Hours and 144 Hours

Specimen A is the carbon steel pipe with no protection or coating. The graphic shows the difference between immersion for 72 hours and 144 hours from the faraday law calculation. The result of 72 hours immersion shows the corrosion rate 0.19478 mmpy. For the result of 144 hours immersion shows the corrosion rate 0.28618 mmpy. The difference of the result is 0.0914 mmpy, the significant difference caused by specimen A did not coated for protection.

This specimen has the biggest corrosion rate. According to the standard of DNV GL Part 4 Chapter 6: 2011, the specimen of the experiment used steel carbon pipe Schedule 40 with diameter of 2 inch or equivalent with 50.8 mm. The standard shows the minimum wall thickness for steel pipe for diameter 48.3 – 51 mm is 3.6 mm. This specimen's lifetime is about ±33 months with corrosion rate 47.20973 mmpy.

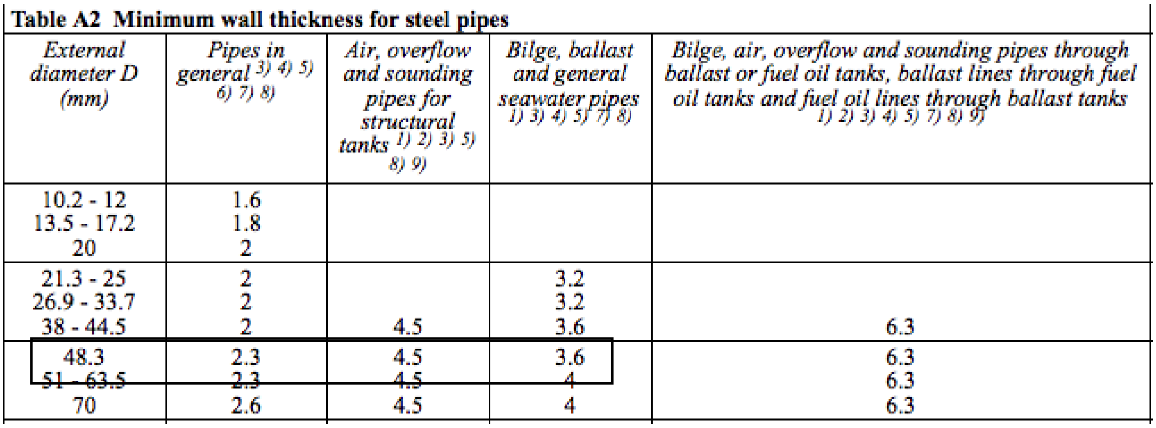
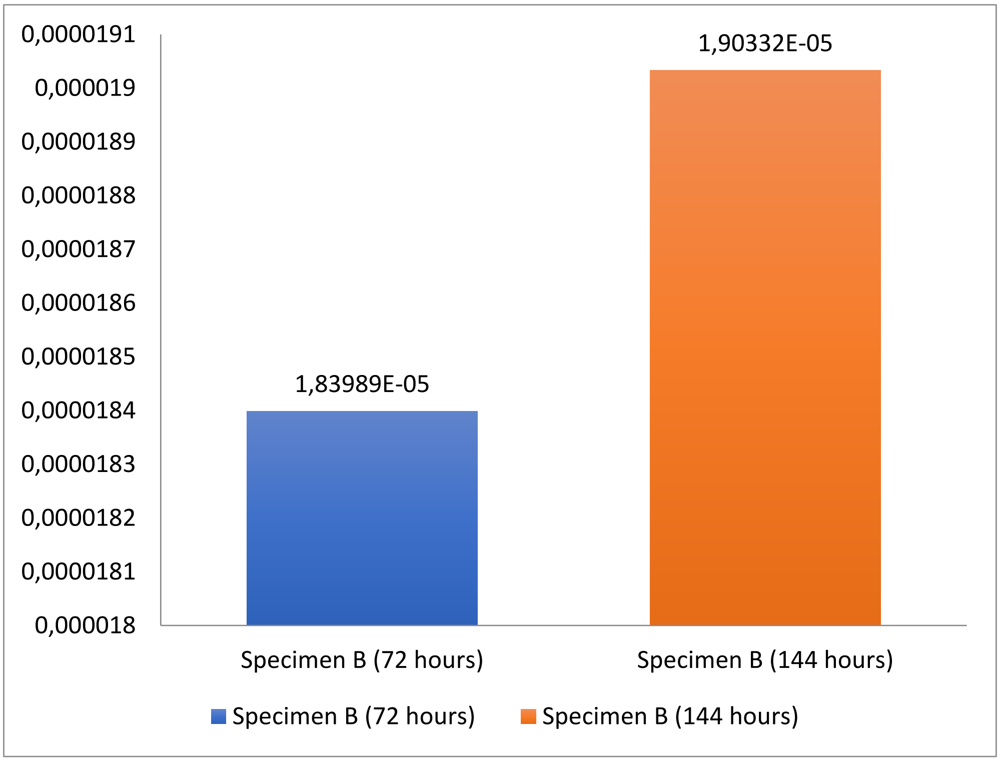


Table A2 Minimum wall thickness for steel pipes

External diameter D (mm)	*Pipes in general* 3) 4) 5) 6) 7) 8)	*Air, overflow and sounding pipes for structural tanks* 1) 2) 3) 5) 8) 9)	*Bilge, ballast and general seawater pipes* 1) 3) 4) 5) 7) 8)	*Bilge, air, overflow and sounding pipes through ballast or fuel oil tanks, ballast lines through fuel oil tanks and fuel oil lines through ballast tanks* 1) 2) 3) 4) 5) 7) 8) 9)
10.2 - 12	1.6			
13.5 - 17.2	1.8			
20	2			
21.3 - 25	2		3.2	
26.9 - 33.7	2		3.2	
38 - 44.5	2	4.5	3.6	6.3
48.3	2.3	4.5	3.6	6.3
51 - 63.5	2.3	4.5	4	6.3
70	2.6	4.5	4	6.3

Figure 4. 10 DNV GL Part 4 Chapter 6

4.5.2. Comparison Specimen B



Graphic 4. 10 Comparison Specimen B for Immersion 72 Hours and 144 Hours

Specimen B is the carbon steel pipe coated with epoxy. The graphic shows the difference between immersion for 72 hours and 144 hours from the faraday law calculation. The result of 72 hours immersion shows the corrosion rate 0.01842 mmpy. For the result of 144 hours immersion shows the corrosion rate 0.019033 mmpy.

This specimen has the specification of ruled by DNV GL 20 about Corrosion Protection of Ships: 2000. The target lifetime of the operation for 5 years for using epoxy coating. According to the result of experiment, the corrosion rate occurs 5.70996 mmppy for 5 years. Meaning the thickness of the pipe wall will be reduced until 45.09004 mm for 5 years and the target can be achieved.

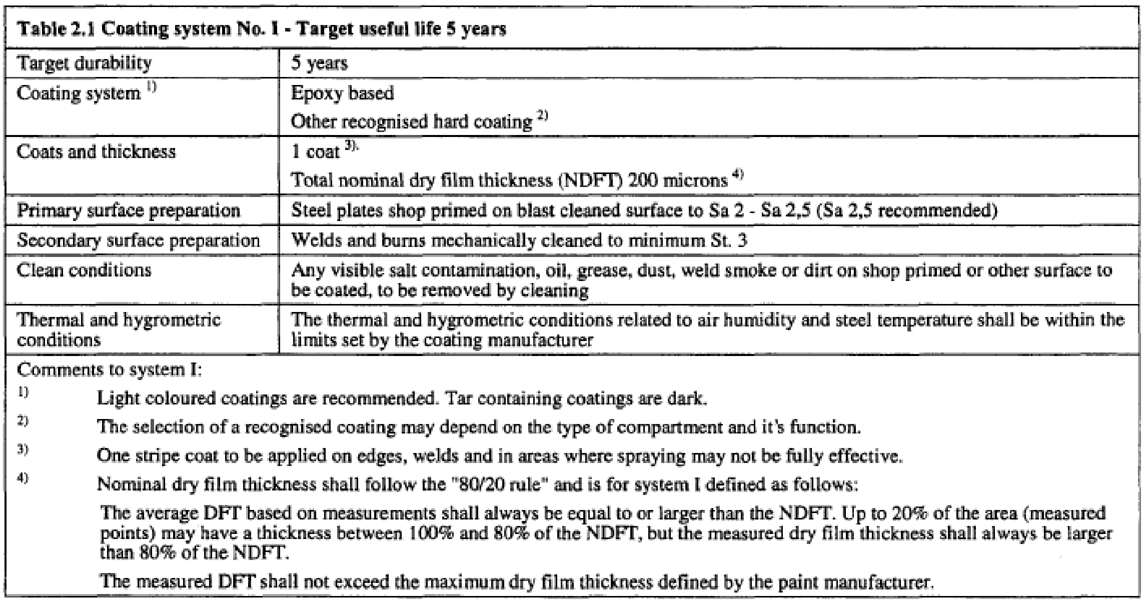


Table 2.1 Coating system No. I - Target useful life 5 years

Target durability	5 years
Coating system 1)	Epoxy based Other recognised hard coating 2)
Coats and thickness	1 coat 3). Total nominal dry film thickness (NDFT) 200 microns 4)
Primary surface preparation	Steel plates shop primed on blast cleaned surface to Sa 2 - Sa 2,5 (Sa 2,5 recommended)
Secondary surface preparation	Welds and burns mechanically cleaned to minimum St. 3
Clean conditions	Any visible salt contamination, oil, grease, dust, weld smoke or dirt on shop primed or other surface to be coated, to be removed by cleaning
Thermal and hygrometric conditions	The thermal and hygrometric conditions related to air humidity and steel temperature shall be within the limits set by the coating manufacturer

Comments to system I:

1) Light coloured coatings are recommended. Tar containing coatings are dark.

2) The selection of a recognised coating may depend on the type of compartment and it's function.

3) One stripe coat to be applied on edges, welds and in areas where spraying may not be fully effective.

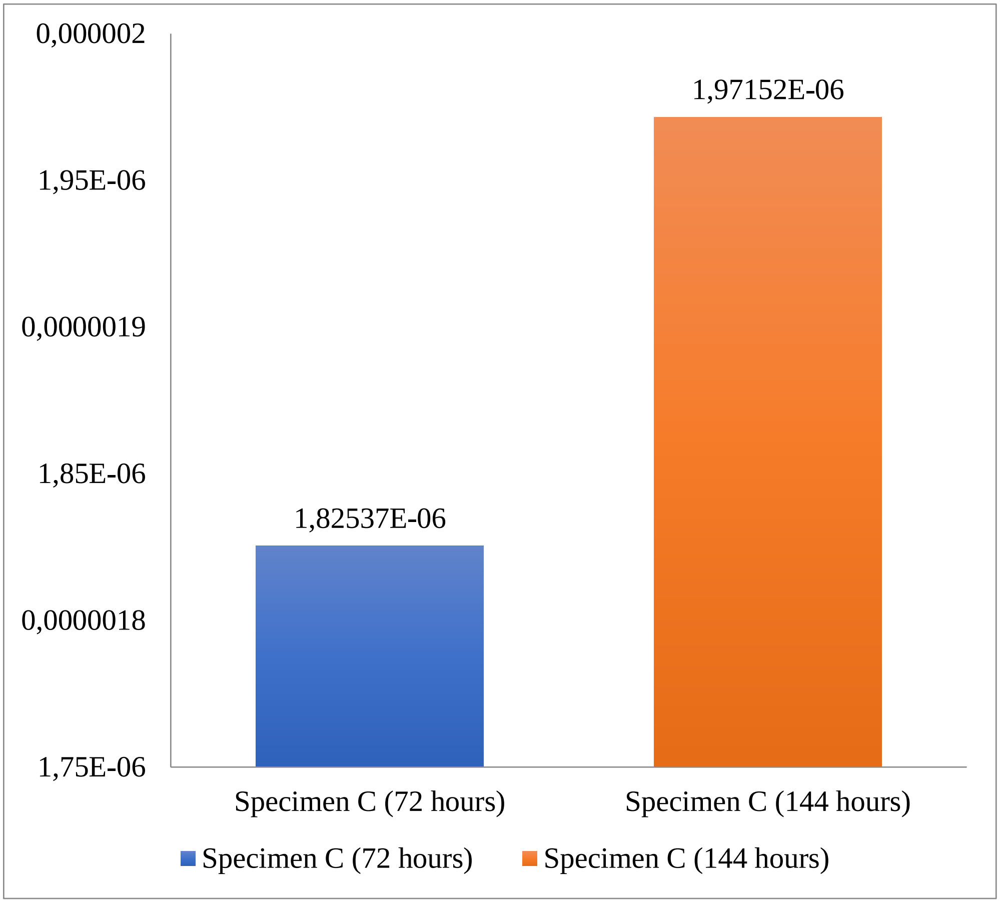
4) Nominal dry film thickness shall follow the "80/20 rule" and is for system I defined as follows:

The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 20% of the area (measured points) may have a thickness between 100% and 80% of the NDFT, but the measured dry film thickness shall always be larger than 80% of the NDFT.

The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer.

Figure 4. 11 DNV GL 20 Corrosion Protection of Ships

4.5.3. Comparison Specimen C

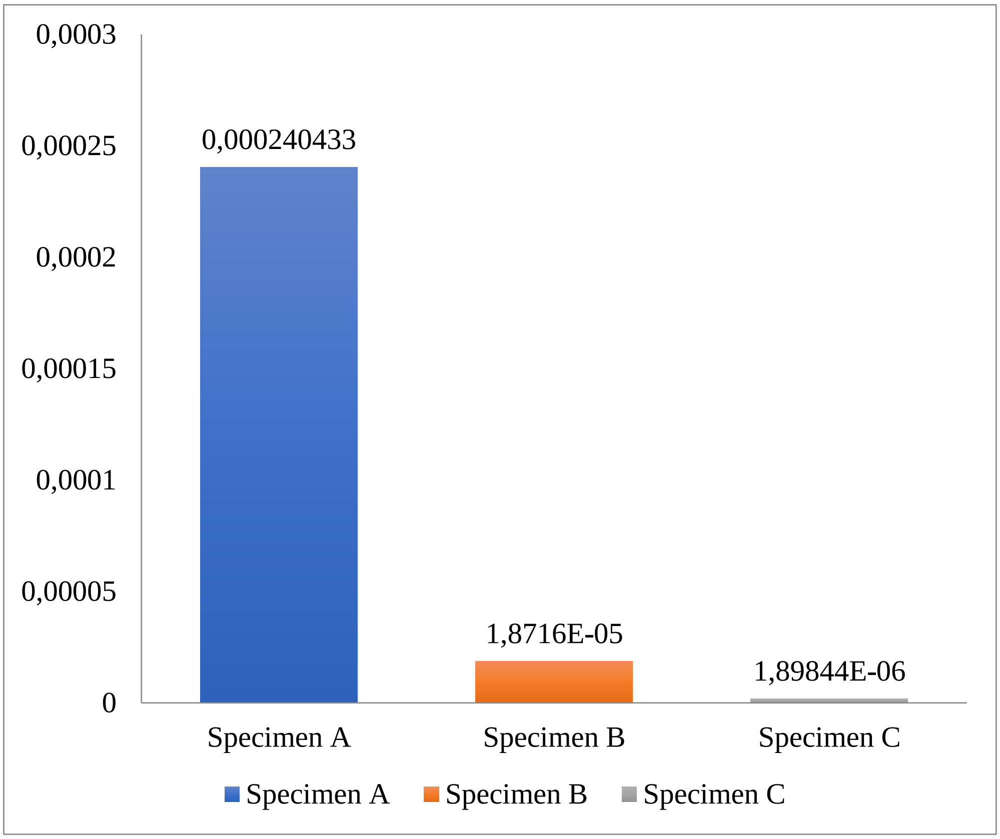


Graphic 4. 11 Comparison Specimen C for Immersion 72 Hours and 144 Hours

Specimen C is the galvanized carbon steel for 80 μ. The graphic shows the difference between immersion for 72 hours and 144 hours from the faraday law calculation. The result of 72 hours immersion shows the corrosion rate 0.001825 mmpy. For the result of 144 hours immersion shows the corrosion rate 0.002634 mmpy.

For all of the specimens, this specimen has the best result of corrosion rate. According to the interview that the author has done, ballast pipe will be replaced with the new one for 15 - 20 years. But for this specimen according to the result, after 20 years the corrosion rate occurs for 2.365819 mmpy, it means the thickness of the wall pipe will be 48.4341808 mm.

4.5.4. Comparison Specimen A, B, and C



Graphic 4. 12 Comparison Specimen A, B, and C for Immersion 144 Hours

The graphic shows the difference between specimen A, B, and C from the calculation of faraday law. The numbers obtained by the average from the first and second immersion calculation. Specimen A is the carbon steel pipe with no protection or coating shows the highest corrosion rate, 0.240433131 mmpy. Followed by specimen B, carbon steel pipe coated with epoxy shows the 0.018716039 mmpy of the corrosion rate. And the last is specimen C shows 0.001898441 mmpy the galvanized carbon steel pipe.

4.6. Relative Corrosion Resistance

The relative corrosion resistance by Fontana (1987) categorized for 6 categories outstanding, excellent, good, fair, poor, and unacceptable. The experiment will be defined by the result of the corrosion rate:

Table 4. 10 Relative Corrosion Resistance

Relative Corrosion Resistance	Approximate Metric Equivalent				
	mpy	mm/year	µm/year	nm/year	pm/sec
Outstanding	< 1	< 0,02	< 25	< 2	< 1
Excellent	1-5	0,02-0,1	25-100	2-10	1-5
Good	20-50	0,1-0,5	100-500	10-50	5-20
Fair	20-50	0,5-1	500-1000	50-100	20-50
Poor	50-200	1,25-5	1000-5000	150-500	50-200
Unacceptable	200+	5+	5000+	500+	200+

Table 4. 11 Relative Corrosion Resistance on Specimen

Faraday Law (mmpy)	Immersion Time (hours)	Relative Corrosion Resistance	Specimen
0.194746712	72	Good	Specimen A (72 hours)
0.018398877	72	Excellent	Specimen B (72 hours)
0.001825366	72	Outstanding	Specimen C (72 hours)
0.28611955	144	Good	Specimen A (144 hours)
0.0190332	144	Excellent	Specimen B1 (144 hours)
0.001971516	144	Outstanding	Specimen C1 (144 hours)

The result of the experiment shows that carbon steel pipe for immersion 72 hours is 0.194746712 mmpy and for 144 hours immersion is 0.28611955 mmpy, both of the results obtained the Good relative corrosion resistance. For the carbon steel pipe with epoxy coating for 72 hours is 0.018398877 mmpy and for 144 hours immersion is 0.0190332 mmpy, both of the results obtained the Excellent relative corrosion resistance. And galvanized carbon steel pipe obtained for the Outstanding relative corrosion resistance, the result on 72 hours immersion is 0.001825366 mmpy and for 144 hours immersion is 0.001971516 mmpy.

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CHAPTER V
CONCLUSION AND SUGGESTION

After doing some experiments, there are some conclusions and suggestions used as evaluation for the next research.

5.1. Conclusion

Based on the experiment results data that has been done, then got the following conclusions:

1) The result of immersion 72 hours in 35% salinity of 35 gram NaCl and 1 liter aquadest for specimen carbon steel pipe is 0.194746712 mmpy, the carbon steel pipe coated with epoxy is 0.018398877 mmpy, and the last for 72 hours immersion is galvanized carbon steel pipe is 0.001825366 mmpy. For 144 hours immersion, the result of the carbon steel pipe is 0.28611955 mmpy, the result of the carbon steel pipe coated with epoxy is 0.0190332 mmpy, and for the galvanized carbon steel pipe is 0.001971516 mmmpy.
2) After immersion for 144 hours, the result of corrosion rate occurs on the carbon steel pipe is 0.28611955 mmpy (highest corrosion rate). And the lowest or the best result of corrosion rate occurs on the galvanized carbon steel pipe, the corrosion rate is 0.001971516 mmpy. This result is caused by the coating treatment for each specimen, the carbon steel pipe treated by chemical cleaning and coated with epoxy. But for the galvanized carbon steel pipe, electrolyte is performed on the carbon steel pipe so the galvanize covered in the electrolyte gap.
3) The relative corrosion resistance divided by 6 categories and the experiment result shows the difference categories by type of the protection. The good relative corrosion resistance obtained by the carbon steel pipe 0.194746712 mmpy for immersion 72 hours and 0.28611955 mmpy for immersion 144 hours on the range of 0,1-0,5 mmpy. For the Excellent relative corrosion resistance occupied by the carbon steel pipe coated with epoxy 0.018398877 mmpy for immersion 72 hours and 0.0190332 mmpy for immersion 144 hours on the range of 0,02-0,1 mmpy. And for the best protection for corrosion is galvanized steel carbon pipe which has the excellent relative corrosion resistance, for the 72 hours immersion is 0.001825366 mmpy and for 144 hours immersion is 0.001971516 mmpy. The relative corrosion resistance excellent range is < 0,02 mmpy.

5.2. Suggestion

In order to obtain more accurate results, in subsequent studies it is advisable to add more specimens with varying coating thickness both on the carbon steel with epoxy coating and galvanized carbon steel

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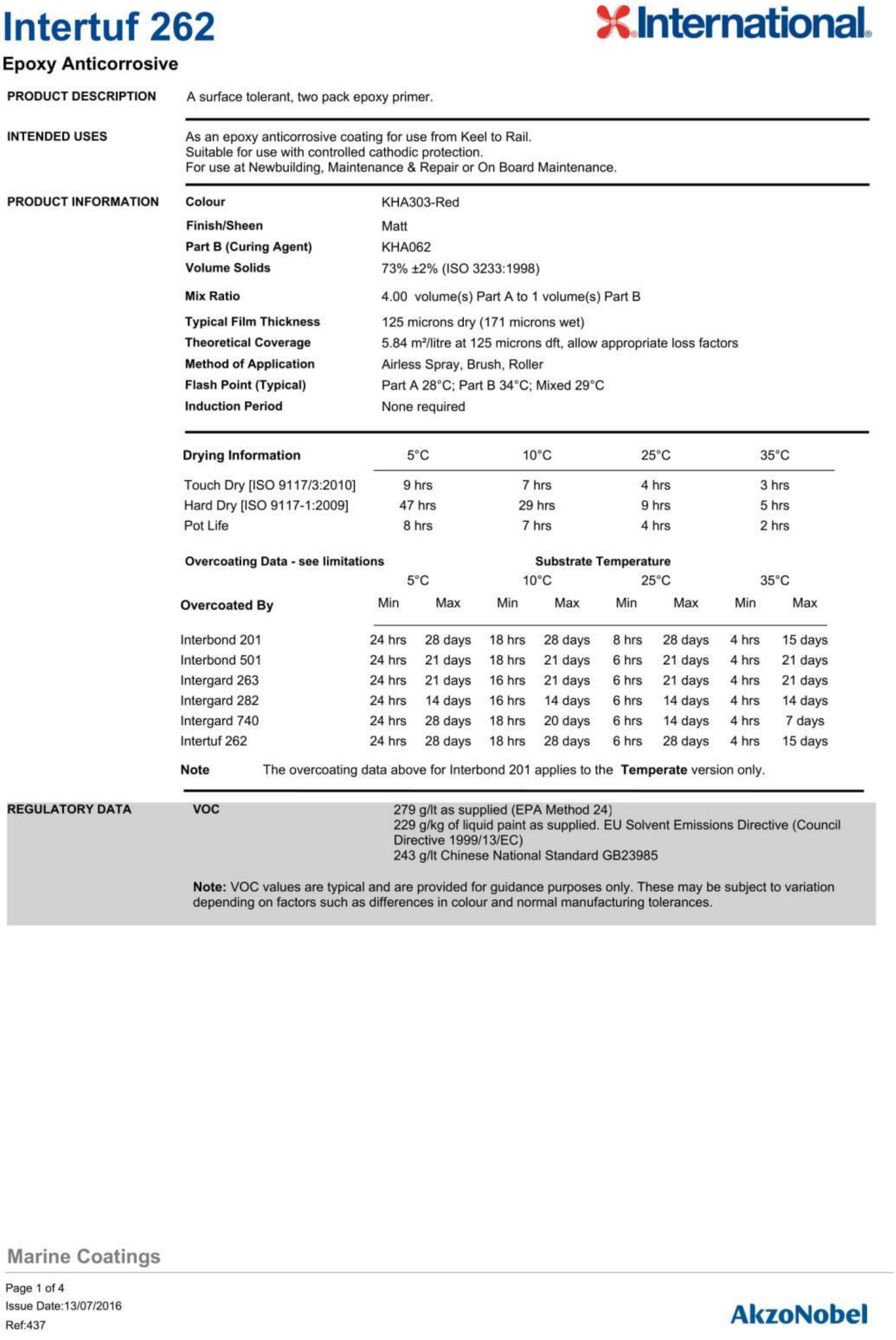
ATTACHMENT



Intertuf 262

Epoxy Anticorrosive

PRODUCT DESCRIPTION	A surface tolerant, two pack epoxy primer.
INTENDED USES	As an epoxy anticorrosive coating for use from Keel to Rail. Suitable for use with controlled cathodic protection. For use at Newbuilding, Maintenance & Repair or On Board Maintenance.

PRODUCT INFORMATION

Colour	KHA303-Red
Finish/Sheen	Matt
Part B (Curing Agent)	KHA062
Volume Solids	73% ±2% (ISO 3233:1998)
Mix Ratio	4.00 volume(s) Part A to 1 volume(s) Part B
Typical Film Thickness	125 microns dry (171 microns wet)
Theoretical Coverage	5.84 m²/litre at 125 microns dft, allow appropriate loss factors
Method of Application	Airless Spray, Brush, Roller
Flash Point (Typical)	Part A 28°C; Part B 34°C; Mixed 29°C
Induction Period	None required

Drying Information	5°C	10°C	25°C	35°C
Touch Dry [ISO 9117/3:2010]	9 hrs	7 hrs	4 hrs	3 hrs
Hard Dry [ISO 9117-1:2009]	47 hrs	29 hrs	9 hrs	5 hrs
Pot Life	8 hrs	7 hrs	4 hrs	2 hrs

Overcoating Data - see limitations **Substrate Temperature**

	5°C		10°C		25°C		35°C	
Overcoated By	Min	Max	Min	Max	Min	Max	Min	Max
Interbond 201	24 hrs	28 days	18 hrs	28 days	8 hrs	28 days	4 hrs	15 days
Interbond 501	24 hrs	21 days	18 hrs	21 days	6 hrs	21 days	4 hrs	21 days
Intergard 263	24 hrs	21 days	16 hrs	21 days	6 hrs	21 days	4 hrs	21 days
Intergard 282	24 hrs	14 days	16 hrs	14 days	6 hrs	14 days	4 hrs	14 days
Intergard 740	24 hrs	28 days	18 hrs	20 days	6 hrs	14 days	4 hrs	7 days
Intertuf 262	24 hrs	28 days	18 hrs	28 days	6 hrs	28 days	4 hrs	15 days

Note The overcoating data above for Interbond 201 applies to the **Temperate** version only.

REGULATORY DATA	**VOC**	279 g/lt as supplied (EPA Method 24) 229 g/kg of liquid paint as supplied. EU Solvent Emissions Directive (Council Directive 1999/13/EC) 243 g/lt Chinese National Standard GB23985

Note: VOC values are typical and are provided for guidance purposes only. These may be subject to variation depending on factors such as differences in colour and normal manufacturing tolerances.

Marine Coatings

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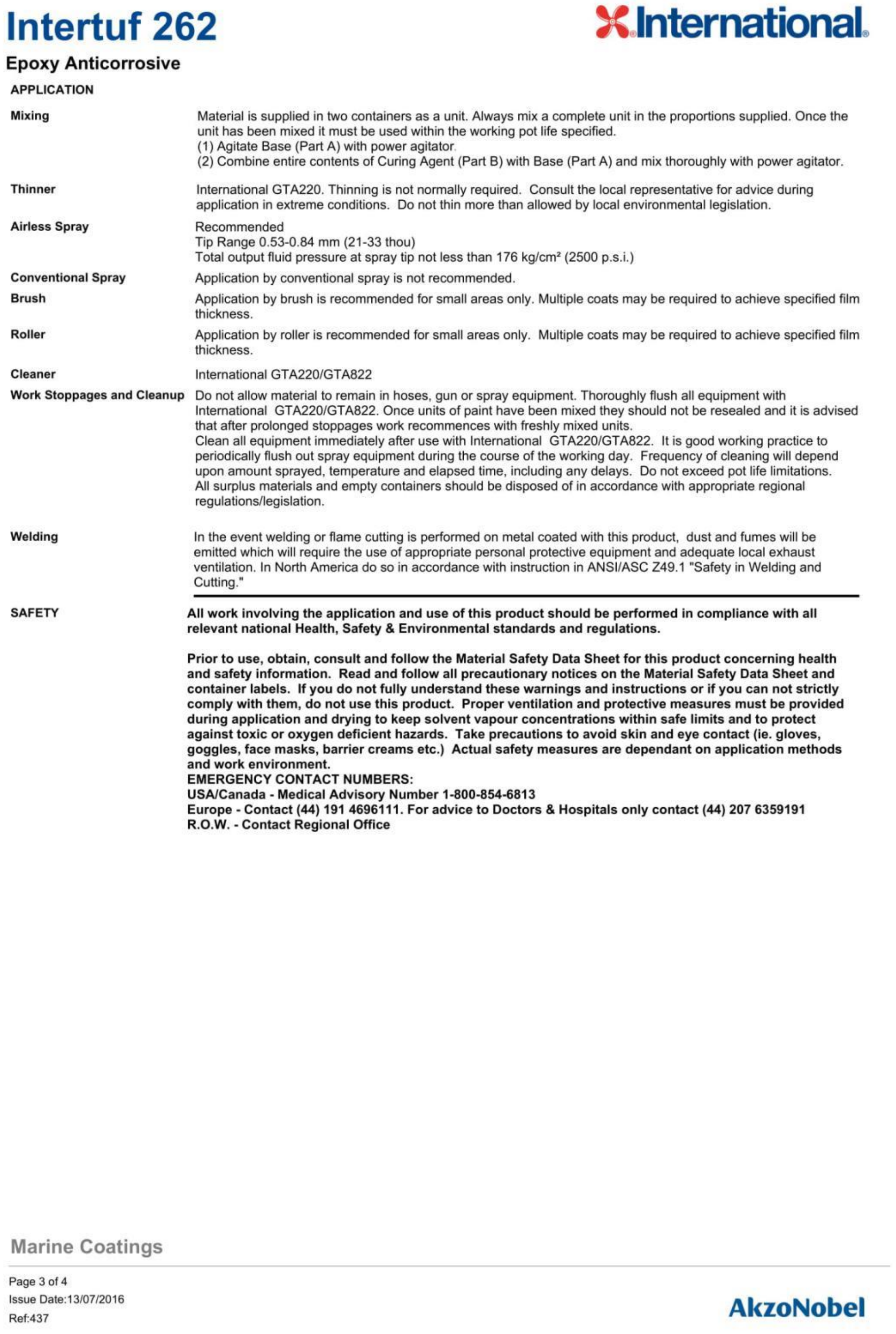


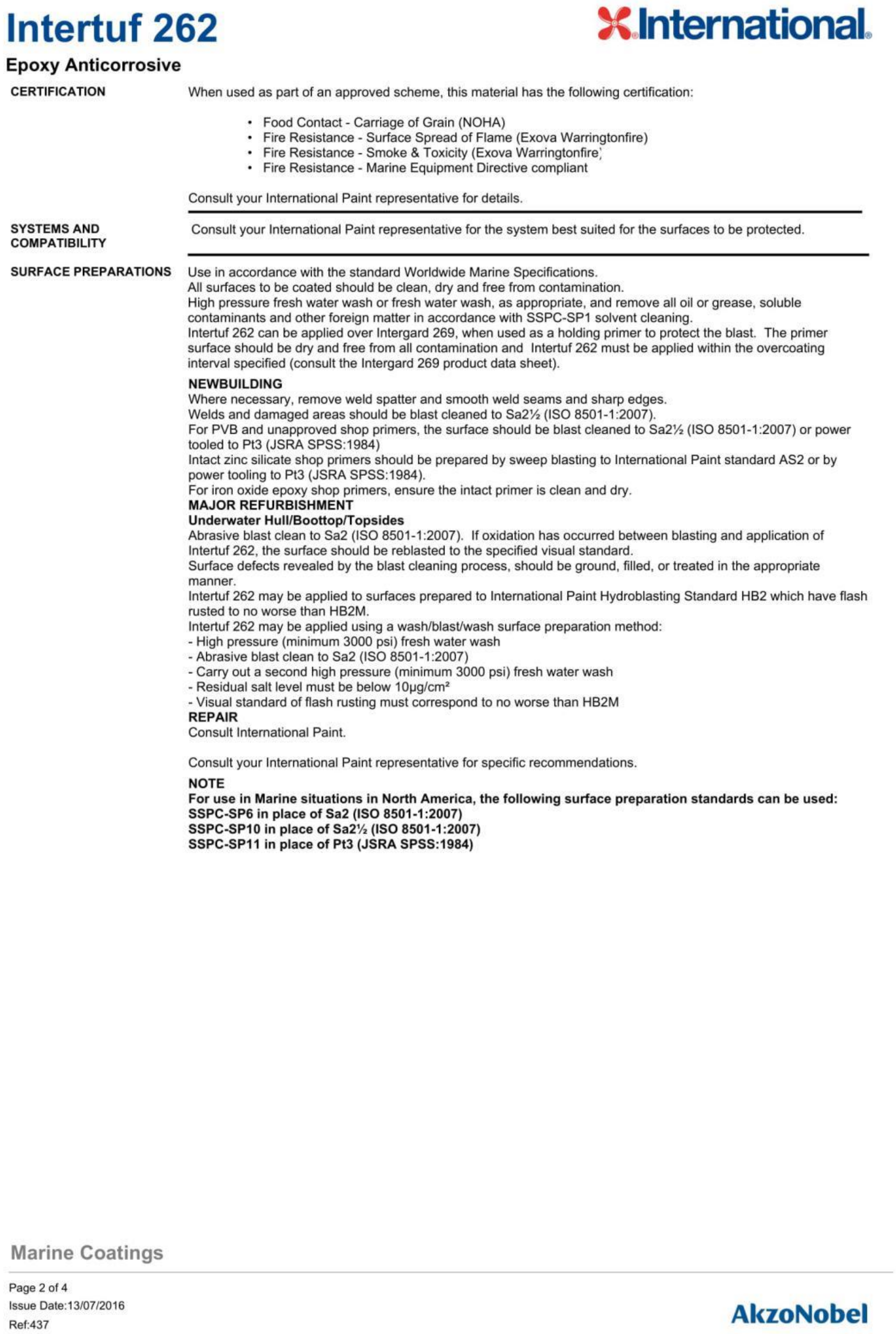
Intertuf 262

International.

Epoxy Anticorrosive

APPLICATION

Mixing	Material is supplied in two containers as a unit. Always mix a complete unit in the proportions supplied. Once the unit has been mixed it must be used within the working pot life specified. (1) Agitate Base (Part A) with power agitator. (2) Combine entire contents of Curing Agent (Part B) with Base (Part A) and mix thoroughly with power agitator.
Thinner	International GTA220. Thinning is not normally required. Consult the local representative for advice during application in extreme conditions. Do not thin more than allowed by local environmental legislation.
Airless Spray	Recommended Tip Range 0.53-0.84 mm (21-33 thou) Total output fluid pressure at spray tip not less than 176 kg/cm² (2500 p.s.i.)
Conventional Spray	Application by conventional spray is not recommended.
Brush	Application by brush is recommended for small areas only. Multiple coats may be required to achieve specified film thickness.
Roller	Application by roller is recommended for small areas only. Multiple coats may be required to achieve specified film thickness.
Cleaner	International GTA220/GTA822
Work Stoppages and Cleanup	Do not allow material to remain in hoses, gun or spray equipment. Thoroughly flush all equipment with International GTA220/GTA822. Once units of paint have been mixed they should not be resealed and it is advised that after prolonged stoppages work recommences with freshly mixed units. Clean all equipment immediately after use with International GTA220/GTA822. It is good working practice to periodically flush out spray equipment during the course of the working day. Frequency of cleaning will depend upon amount sprayed, temperature and elapsed time, including any delays. Do not exceed pot life limitations. All surplus materials and empty containers should be disposed of in accordance with appropriate regional regulations/legislation.
Welding	In the event welding or flame cutting is performed on metal coated with this product, dust and fumes will be emitted which will require the use of appropriate personal protective equipment and adequate local exhaust ventilation. In North America do so in accordance with instruction in ANSI/ASC Z49.1 "Safety in Welding and Cutting."
SAFETY	**All work involving the application and use of this product should be performed in compliance with all relevant national Health, Safety & Environmental standards and regulations.** **Prior to use, obtain, consult and follow the Material Safety Data Sheet for this product concerning health and safety information. Read and follow all precautionary notices on the Material Safety Data Sheet and container labels. If you do not fully understand these warnings and instructions or if you can not strictly comply with them, do not use this product. Proper ventilation and protective measures must be provided during application and drying to keep solvent vapour concentrations within safe limits and to protect against toxic or oxygen deficient hazards. Take precautions to avoid skin and eye contact (ie. gloves, goggles, face masks, barrier creams etc.) Actual safety measures are dependant on application methods and work environment.** **EMERGENCY CONTACT NUMBERS:** **USA/Canada - Medical Advisory Number 1-800-854-6813** **Europe - Contact (44) 191 4696111. For advice to Doctors & Hospitals only contact (44) 207 6359191** **R.O.W. - Contact Regional Office**



Intertuf 262

International.

Epoxy Anticorrosive

CERTIFICATION

When used as part of an approved scheme, this material has the following certification:

- Food Contact - Carriage of Grain (NOHA)
- Fire Resistance - Surface Spread of Flame (Exova Warringtonfire)
- Fire Resistance - Smoke & Toxicity (Exova Warringtonfire)
- Fire Resistance - Marine Equipment Directive compliant

Consult your International Paint representative for details.

SYSTEMS AND COMPATIBILITY

Consult your International Paint representative for the system best suited for the surfaces to be protected.

SURFACE PREPARATIONS

Use in accordance with the standard Worldwide Marine Specifications.
All surfaces to be coated should be clean, dry and free from contamination.
High pressure fresh water wash or fresh water wash, as appropriate, and remove all oil or grease, soluble contaminants and other foreign matter in accordance with SSPC-SP1 solvent cleaning.
Intertuf 262 can be applied over Intergard 269, when used as a holding primer to protect the blast. The primer surface should be dry and free from all contamination and Intertuf 262 must be applied within the overcoating interval specified (consult the Intergard 269 product data sheet).

NEWBUILDING
Where necessary, remove weld spatter and smooth weld seams and sharp edges.
Welds and damaged areas should be blast cleaned to Sa2½ (ISO 8501-1:2007).
For PVB and unapproved shop primers, the surface should be blast cleaned to Sa2½ (ISO 8501-1:2007) or power tooled to Pt3 (JSRA SPSS:1984)
Intact zinc silicate shop primers should be prepared by sweep blasting to International Paint standard AS2 or by power tooling to Pt3 (JSRA SPSS:1984).
For iron oxide epoxy shop primers, ensure the intact primer is clean and dry.
MAJOR REFURBISHMENT
Underwater Hull/Boottop/Topsides
Abrasive blast clean to Sa2 (ISO 8501-1:2007). If oxidation has occurred between blasting and application of Intertuf 262, the surface should be reblasted to the specified visual standard.
Surface defects revealed by the blast cleaning process, should be ground, filled, or treated in the appropriate manner.
Intertuf 262 may be applied to surfaces prepared to International Paint Hydroblasting Standard HB2 which have flash rusted to no worse than HB2M.
Intertuf 262 may be applied using a wash/blast/wash surface preparation method:
- High pressure (minimum 3000 psi) fresh water wash
- Abrasive blast clean to Sa2 (ISO 8501-1:2007)
- Carry out a second high pressure (minimum 3000 psi) fresh water wash
- Residual salt level must be below 10µg/cm²
- Visual standard of flash rusting must correspond to no worse than HB2M

REPAIR
Consult International Paint.

Consult your International Paint representative for specific recommendations.

NOTE
For use in Marine situations in North America, the following surface preparation standards can be used:
SSPC-SP6 in place of Sa2 (ISO 8501-1:2007)
SSPC-SP10 in place of Sa2½ (ISO 8501-1:2007)
SSPC-SP11 in place of Pt3 (JSRA SPSS:1984)

Intertuf 262

Epoxy Anticorrosive

LIMITATIONS

A system of Intertuf 262 followed by Intergard 263 may be used for the spot repair or upgrade of the following substrates:
Spot Repair (Suitable Substrates): - Epoxy, Coal Tar Epoxy, Chlorinated Rubber, Vinyl Tar, Tar-free Vin
Substrates not suitable for repair : - Bituminous
Upgrade (Suitable Substrates): - Epoxy, Coal Tar Epoxy, Chlorinated Rubbe
Substrates not suitable for upgrading:- Vinyl Tar, Tar-free Vinyl, Bituminou
Feathered overlap areas must be kept to a minimum.

Overcoating information is given for guidance only and is subject to regional variation depending upon local climate and environmental conditions. Consult your local International Paint representative for specific recommendations. Apply in good weather. Temperature of the surface to be coated must be at least 3°C above the dew point. For optimum application properties bring the material to 21-27°C, unless specifically instructed otherwise, prior to mixing and application. Unmixed material (in closed containers) should be maintained in protected storage in accordance with information given in the STORAGE Section of this data sheet. Technical and application data herein is for the purpose of establishing a general guideline of the coating application procedures. Test performance results were obtained in a controlled laboratory environment and International Paint makes no claim that the exhibited published test results, or any other tests, accurately represent results found in all field environments. As application, environmental and design factors can vary significantly, due care should be exercised in the selection, verification of performance and use of the coating.

Under certain climatic conditions, particularly at low temperature and high humidity, amine bloom can occur on the coating surface during drying. In order to prevent this, an induction period of 30 minutes is recommended between mixing and paint application at temperatures below 25°C.

UNIT SIZE

Unit Size	Part A		Part B	
	Vol	Pack	Vol	Pack
20 lt	16 lt	20 lt	4 lt	5 lt

For availability of other unit sizes consult International Paint

UNIT SHIPPING WEIGHT (TYPICAL)

Unit Size	Unit Weight
20 lt	29.03 Kg

STORAGE

Shelf Life	12 months at 25°C. Subject to re-inspection thereafter. Store in dry, shaded conditions away from sources of heat and ignition.

WORLDWIDE AVAILABILITY

Other colours may be available in specific countries, consult International Paint.

IMPORTANT NOTE

The information in this data sheet is not intended to be exhaustive; any person using the product for any purpose other than that specifically recommended in this data sheet without first obtaining written confirmation from us as to the suitability of the product for the intended purpose does so at their own risk. All advice given or statements made about the product (whether in this data sheet or otherwise) is correct to the best of our knowledge but we have no control over the quality or the condition of the substrate or the many factors affecting the use and application of the product. Therefore, unless we specifically agree in writing to do so, we do not accept any liability at all for the performance of the product or for (subject to the maximum extent permitted by law) any loss or damage arising out of the use of the product. We hereby disclaim any warranties or representations, express or implied, by operation of law or otherwise, including, without limitation, any implied warranty of merchantability or fitness for a particular purpose. All products supplied and technical advice given are subject to our Conditions of Sale. You should request a copy of this document and review it carefully. The information contained in this data sheet is liable to modification from time to time in the light of experience and our policy of continuous development. It is the user's responsibility to check with their local representative that this data sheet is current prior to using the product.

This Technical Data Sheet is available on our website at www.international-marine.com or www.international-pc.com, and should be the same as this document. Should there be any discrepancies between this document and the version of the Technical Data Sheet that appears on the website, then the version on the website will take precedence.

www.international-marine.com

ASTM G102

Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements

Designation: G 102 – 89 (Reapproved 1994)$^{\epsilon 1}$

Standard Practice for
Calculation of Corrosion Rates and Related Information from Electrochemical Measurements[1]

This standard is issued under the fixed designation G 102; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

$^{\epsilon 1}$ NOTE—Section 6 was added editorially in May 1994.

1. Scope

1.1 This practice is intended to provide guidance in converting the results of electrochemical measurements to rates of uniform corrosion. Calculation methods for converting corrosion current density values to either mass loss rates or average penetration rates are given for most engineering alloys. In addition, some guidelines for converting polarization resistance values to corrosion rates are provided.

2. Referenced Documents

2.1 *ASTM Standards:*

D 2776 Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Electrical Methods)[2]

G 5 Reference Test Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements[3]

G 59 Practice for Conducting Potentiodynamic Polarization Resistance Measurements[3]

3. Significance and Use

3.1 Electrochemical corrosion rate measurements often provide results in terms of electrical current. Although the conversion of these current values into mass loss rates or penetration rates is based on Faraday's Law, the calculations can be complicated for alloys and metals with elements having multiple valence values. This practice is intended to provide guidance in calculating mass loss and penetration rates for such alloys. Some typical values of equivalent weights for a variety of metals and alloys are provided.

3.2 Electrochemical corrosion rate measurements may provide results in terms of electrical resistance. The conversion of these results to either mass loss or penetration rates requires additional electrochemical information. Some approaches for estimating this information are given.

3.3 Use of this practice will aid in producing more consistent corrosion rate data from electrochemical results. This will make results from different studies more comparable and minimize calculation errors that may occur in transforming electrochemical results to corrosion rate values.

4. Corrosion Current Density

4.1 Corrosion current values may be obtained from galvanic cells and polarization measurements, including Tafel extrapolations or polarization resistance measurements. (See Reference Test Method G 5 and Practice G 59 for examples.) The first step is to convert the measured or estimated current value to current density. This is accomplished by dividing the total current by the geometric area of the electrode exposed to the solution. It is assumed that the current distributes uniformly across the area used in this calculation. In the case of galvanic couples, the exposed area of the anodic specimen should be used. This calculation may be expressed as follows:

$$i_{cor} = \frac{I_{cor}}{A} \tag{1}$$

where:

i_{cor} = corrosion current density, μA/cm^2,
I_{cor} = total anodic current, μA, and
A = exposed specimen area, cm^2.

Other units may be used in this calculation. In some computerized polarization equipment, this calculation is made automatically after the specimen area is programmed into the computer. A sample calculation is given in Appendix X1.

4.2 *Equivalent Weight*—Equivalent weight, EW, may be thought of as the mass of metal in grams that will be oxidized by the passage of one Faraday (96 489 ± 2 C (amp-sec)) of electric charge.

NOTE 1—The value of EW is not dependent on the unit system chosen and so may be considered dimensionless.

For pure elements, the equivalent weight is given by:

$$EW = \frac{W}{n} \tag{2}$$

where:

W = the atomic weight of the element, and
n = the number of electrons required to oxidize an atom of the element in the corrosion process, that is, the valence of the element.

4.3 For alloys, the equivalent weight is more complex. It is usually assumed that the process of oxidation is uniform and does not occur selectively to any component of the alloy. If this is not true, then the calculation approach will need to be adjusted to reflect the observed mechanism. In addition, some rationale must be adopted for assigning values of n to

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[1] This practice is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.11 on Electrochemical Measurements in Corrosion Testing.

Current edition approved Feb. 24, 1989. Published May 1989.

[2] *Discontinued*—See *1990 Annual Book of ASTM Standards*, Vol 03.02.

[3] *Annual Book of ASTM Standards*, Vol 03.02.

the elements in the alloy because many elements exhibit more than one valence value.

4.4 To calculate the alloy equivalent weight, the following approach may be used. Consider a unit mass of alloy oxidized. The electron equivalent for 1 g of an alloy, Q is then:

$$Q = \Sigma \frac{\mathrm{nifi}}{\mathrm{Wi}} \tag{3}$$

where:

fi = the mass fraction of the i^{th} element in the alloy,
Wi = the atomic weight of the i^{th} element in the alloy, and
ni = the valence of the i^{th} element of the alloy.

Therefore, the alloy equivalent weight, EW, is the reciprocal of this quantity:

$$EW = \frac{1}{\Sigma \frac{\mathrm{nifi}}{\mathrm{Wi}}} \tag{4}$$

Normally only elements above 1 mass percent in the alloy are included in the calculation. In cases where the actual analysis of an alloy is not available, it is conventional to use the mid-range of the composition specification for each element, unless a better basis is available. A sample calculation is given in Appendix X2 **(1)**.[4]

4.5 Valence assignments for elements that exhibit multiple valences can create uncertainty. It is best if an independent technique can be used to establish the proper valence for each alloying element. Sometimes it is possible to analyze the corrosion products and use those results to establish the proper valence. Another approach is to measure or estimate the electrode potential of the corroding surface. Equilibrium diagrams showing regions of stability of various phases as a function of potential and pH may be created from thermodynamic data. These diagrams are known as Potential-pH (Pourbaix) diagrams and have been published by several authors **(2, 3)**. The appropriate diagrams for the various alloying elements can be consulted to estimate the stable valence of each element at the temperature, potential, and pH of the contacting electrolyte that existed during the test.

NOTE 2—Some of the older publications used inaccurate thermodynamic data to construct the diagrams and consequently they are in error.

4.6 Some typical values of EW for a variety of metals and alloys are given in Table 1.

4.7 *Calculation of Corrosion Rate*—Faraday's Law can be used to calculate the corrosion rate, either in terms of penetration rate (CR) or mass loss rate (MR) **(4)**:

$$CR = K_1 \frac{i_{cor}}{\rho} EW \tag{5}$$

$$MR = K_2\, i_{cor}\, EW \tag{6}$$

where:

CR is given in mm/yr, i_{cor} in µA/cm^2,
K_1 = 3.27 × 10^{-3}, mm g/µA cm yr (Note 3),
ρ = density in g/cm^3, (see Practice G 1 for density values for many metals and alloys used in corrosion testing),
MR = g/m^{2}d, and
K_2 = 8.954 × 10^{-3}, g cm^2/µA m^2 d (Note 3).

NOTE 3—*EW* is considered dimensionless in these calculations.

Other values for K_1 and K_2 for different unit systems are given in Table 2.

4.8 Errors that may arise from this procedure are discussed below.

4.8.1 Assignment of incorrect valence values may cause serious errors **(5)**.

4.8.2 The calculation of penetration or mass loss from electrochemical measurements, as described in this standard, assumes that uniform corrosion is occurring. In cases where non-uniform corrosion processes are occurring, the use of these methods may result in a substantial underestimation of the true values.

4.8.3 Alloys that include large quantities of metalloids or oxidized materials may not be able to be treated by the above procedure.

4.8.4 Corrosion rates calculated by the method above where abrasion or erosion is a significant contributor to the metal loss process may yield significant underestimation of the metal loss rate.

5. Polarization Resistance

5.1 Polarization resistance values may be approximated from either potentiodynamic measurements near the corrosion potential (see Practice G 59) or stepwise potentiostatic polarization using a single small potential step, ΔE, usually either 10 mV or −10 mV, (see Test Method D 2776). Values of ±5 and ±20 mV are also commonly used. In this case, the specimen current, ΔI, is measured after steady state occurs, and $\Delta E/\Delta I$ is calculated. Potentiodynamic measurements yield curves of I versus E and the reciprocal of the slope of the curve (dE/dI) at the corrosion potential is measured. In most programmable potentiodynamic polarization equipment, the current is converted to current density automatically and the resulting plot is of i versus E. In this case, the polarization resistance is given by dE/di at the corrosion potential and 5.2 is not applicable.

5.2 It is necessary to multiply the dE/dI or ΔE/ΔI value calculated above by the exposed specimen geometric area to obtain the polarization resistance. This is equivalent to the calculation shown in 4.1 for current density.

5.3 The Stern-Geary constant B must be estimated or calculated to convert polarization resistance values to corrosion current density **(6, 8)**.

5.3.1 Calculate Stern-Geary constants from known Tafel slopes where both cathodic and anodic reactions are activation controlled, that is, there are distinct linear regions near the corrosion potential on an E log i plot:

$$B = \frac{ba\, bc}{2.303\,(ba + bc)} \tag{7}$$

where:

ba = slope of the anodic Tafel reaction, when plotted on base 10 logarithmic paper in V/decade,
bc = slope of the cathodic Tafel reaction when plotted on base 10 logarithmic paper in V/decade, and
B = Stern-Geary constant, V.

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[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.

TABLE 1 Equivalent Weight Values for a Variety of Metals and Alloys

Common Designation	UNS	Elements w/Constant Valence	Lowest		Second		Third		Fourth	
			Variable Valence	Equivalent Weight	Variable Valence	Equivalent Weight	Element/ Valence	Equivalent Weight	Element/ Valence	Equivalent Weight
Aluminum Alloys:										
AA1100	A91100	Al/3		8.99						
AA2024	A92024	Al/3, Mg/2	Cu/1	9.38	Cu/2	9.32				
AA2219	A92219	Al/3	Cu/1	9.51	Cu/2	9.42				
AA3003	A93003	Al/3	Mn/2	9.07	Mn/4	9.03	Mn 7	8.98		
AA3004	A93004	Al/3, Mg/2	Mn/2	9.09	Mn/4	9.06	Mn 7	9.00		
AA5005	A95005	Al/3, Mg/2		9.01						
AA5050	A95050	Al/3, Mg/2		9.03						
AA5052	A95052	Al/3, Mg/2		9.05						
AA5083	A95083	Al/3, Mg/2		9.09						
AA5086	A95086	Al/3, Mg/2		9.09						
AA5154	A95154	Al/3, Mg/2		9.08						
AA5454	A95454	Al/3, Mg/2		9.06						
AA5456	A95456	Al/3, Mg/2		9.11						
AA6061	A96061	Al/3, Mg/2		9.01						
AA6070	A96070	Al/3, Mg/2, Si/4		8.98						
AA6101	A96161	Al/3		8.99						
AA7072	A97072	Al/3, Zn/2		9.06						
AA7075	A97075	Al/3, Zn/2, Mg/2	Cu/1	9.58	Cu/2	9.55				
AA7079	A97079	Al/3, Zn/2, Mg/2		9.37						
AA7178	A97178	Al/3, Zn/2, Mg/2	Cu/1	9.71	Cu/2	9.68				
Copper Alloys:										
CDA110	C11000		Cu/1	63.55	Cu/2	31.77				
CDA220	C22000	Zn/2	Cu/1	58.07	Cu/2	31.86				
CDA230	C23000	Zn/2	Cu/1	55.65	Cu/2	31.91				
CDA260	C26000	Zn/2	Cu/1	49.51	Cu/2	32.04				
CDA280	C28000	Zn/2	Cu/1	46.44	Cu/2	32.11				
CDA444	C44300	Zn/2	Cu/1, Sn/2	50.42	Cu/1, Sn/4	50.00	Cu/2, Sn/4	32.00		
CDA687	C68700	Zn/2, Al/3	Cu/1	48.03	Cu/2	30.29				
CDA608	C60800	Al/3	Cu/1	47.114	Cu/2	27.76				
CDA510	C51000		Cu/1, Sn/2	63.32	Cu/1, Sn/4	60.11	Cu/2, Sn/4	31.66		
CDA524	C52400		Cu/1, Sn/2	63.10	Cu/1, Sn/4	57.04	Cu/2, Sn/4	31.55		
CDA655	C65500	Si/4	Cu/1	50.21	Cu/2	28.51				
CDA706	C70600	Ni/2	Cu/1	56.92	Cu/2	31.51				
CDA715	C71500	Ni/2	Cu/1	46.69	Cu/2	30.98				
CDA752	C75200	Ni/2, Zn/2	Cu/1	46.38	Cu/2	31.46				
Stainless Steels:										
304	S30400	Ni/2	Fe/2, Cr/3	25.12	Fe/3, Cr/3	18.99	Fe/3, Cr/6	15.72		
321	S32100	Ni/2	Fe/2, Cr/3	25.13	Fe/3, Cr/3	19.08	Fe/3, Cr/6	15.78		
309	S30900	Ni/2	Fe/2, Cr/3	24.62	Fe/3, Cr/3	19.24	Fe/3, Cr/6	15.33		
310	S31000	Ni/2	Fe/2, Cr/3	24.44	Fe/3, Cr/3	19.73	Fe/3, Cr/6	15.36		
316	S31600	Ni/2	Fe/2, Cr/3, Mo/3	25.50	Fe/2, Cr/3, Mo/4	25.33	Fe/3, Cr/6, Mo/6	19.14	Fe/3, Cr/6, Mo/6	16.111
317	S31700	Ni/2	Fe/2, Cr/3, Mo/3	25.26	Fe/2, Cr/3, Mo/4	25.03	Fe/3, Cr/3, Mo/6	19.15	Fe/3, Cr/6, Mo/6	15.82
410	S41000		Fe/2, Cr/3	25.94	Fe/3, Cr/3	18.45	Fe/3, Cr/6	16.28		
430	S43000		Fe/2, Cr/3	25.30	Fe/3, Cr/3	18.38	Fe/3, Cr/6	15.58		
446	S44600		Fe/2, Cr/3	24.22	Fe/3, Cr/3	18.28	Fe/3, Cr/6	14.46		
20CB3^A	N08020	Ni/2	Fe/2, Cr/3, Mo/3, Cu/1	23.98	Fe/2, Cr/3, Mo/ 4, Cu/1	23.83	Fe/3, Cr/3, Mo/ 6, Cu/2	18.88	Fe/3, Cr/6, Mo/6, Cu/2	15.50
Nickel Alloys:										
200	N02200		Ni/2	29.36	Ni/3	19.57				
400	N04400	Ni/2	Cu/1	35.82	Cu/2	30.12				
600	N06600	Ni/2	Fe/2, Cr/3	26.41	Fe/3, Cr/3	25.44	Fe/3, Cr/6	20.73		
800	N08800	Ni/2	Fe/2, Cr/3	25.10	Fe/3, Cr/3	20.76	Fe/3, Cr/6	16.59		
825	N08825	Ni/2	Fe/2, Cr/3, Mo/3, Cu/1	25.52	Fe/2, Cr/3, Mo/ 4, Cu/1	25.32	Fe/3, Cr/3, Mo/ 6, Cu/2	21.70	Fe/3, Cr/6, Mo/6, Cu/2	17.10

TABLE 1 *Continued*

Common Designation	UNS	Elements w/Constant Valence	Lowest		Second		Third		Fourth	
			Variable Valence	Equivalent Weight	Variable Valence	Equivalent Weight	Element/ Valence	Equivalent Weight	Element/ Valence	Equivalent Weight
Nickel Alloys (continued):										
B	N10001	Ni/2	Mo/3, Fe/2	30.05	Mo/4, Fe/2	27.50	Mo/6, Fe/2	23.52	Mo/6, Fe/3	23.23
C-22[B]	N06022	Ni/2	Fe/2, Cr/3, Mo/3, W/4	26.04	Fe/2, Cr/3, Mo/4, W/4	25.12	Fe/2, Cr/3, Mo/6, W/6	23.28	Fe/3, Cr/6, Mo/6, W/6	17.88
C-276	N10276	Ni/2	Fe/2, Cr/3, Mo/3, W/4	27.09	Cr/3, Mo/4	25.90	Fe/2, Cr/3, Mo/6, W/6	23.63	Fe/3, Cr/6, Mo/6, W/6	19.14
G	N06007	Ni/2	(1)	25.46	(2)	22.22	(3)	22.04	(4)	17.03
Carbon Steel:			Fe/2	27.92	Fe/3	18.62				
(1) = Fe/2, Cr/3, Mo/3, Cu/1, Nb/4, Mn/2			(3) = Fe/3, Cr/3, Mo/6, Cu/2, Nb/5, Mn/2							
(2) = Fe/2, Cr/3, Mo/4, Cu/2, Nb/5, Mn/2			(4) = Fe/3, Cr/6, Mo/6, Cu/2, Nb/5, Mn/4							
Other Metals:										
Mg	M14142	Mg/2		12.15						
Mo	R03600		Mo/3	31.98	Mo/4	23.98	Mo/6	15.99		
Ag	P07016		Ag/1	107.87	Ag/2	53.93				
Ta	R05210	Ta/5		36.19						
Sn	L13002		Sn/2	59.34	Sn/4	29.67				
Ti	R50400		Ti/2	23.95	Ti/3	15.97	Ti/4	11.98		
Zn	Z19001	Zn/2		32.68						
Zr	R60701	Zr/4		22.80						
Pb	L50045		Pb/2	103.59	Pb/4	51.80				

[A] Registered trademark Carpenter Technology.

[B] Registered trademark Haynes International.

NOTE 1—Alloying elements at concentrations below 1 % by mass were not included in the calculation, for example, they were considered part of the basis metal.

NOTE 2—Mid-range values were assumed for concentrations of alloying elements.

NOTE 3—Only consistent valence groupings were used.

NOTE 4—Equation (4) was used to make these calculations.

TABLE 2 Values of Constants for Use in Faraday's Equation Rate

A

Penetration Rate Unit (CR)	I_{cor} Unit	ρ Unit	K_1	Units of K_1[A]
mpy	µA/cm²	g/cm³	0.1288	mpy g/µA cm
mm/yr[B]	A/m²[B]	kg/m³[B]	327.2	mm kg/A m y
mm/yr[B]	µA/cm²	g/cm³	3.27×10^{-3}	mm g/µA cm y

B

Mass Loss Rate Unit	I_{cor} Unit	K_2	Units of K_2[A]
g/m²d[B]	A/m²[B]	0.8953	g/Ad
mg/dm²d (mdd)	µA/cm²	0.0895	mg cm²/µA dm² d
mg/dm²d (mdd)	A/m²[B]	8.953×10^{-3}	mg m²/A dm² d

[A] EW is assumed to be dimensionless.

[B] SI unit.

5.3.2 In cases where one of the reactions is purely diffusion controlled, the Stern-Geary constant may be calculated:

$$B = \frac{b}{2.303} \tag{8}$$

where:

b = the activation controlled Tafel slope in V/decade.

It should be noted in this case that the corrosion current density will be equal to the diffusion limited current density. A sample calculation is given in Appendix X4.

Cases where both activation and diffusion effects are similar in magnitude are known as mixed control. The reaction under mixed control will have an apparently larger b value than predicted for an activation control, and a plot of E versus log I will tend to curve to an asymptote parallel to the potential axis. The estimation of a B value for situations involving mixed control requires more information in general and is beyond the scope of this standard. In general, Eqs 7 and 8 may be used, and the corrosion rate calculated by these two approximations may be used as lower and upper limits of the true rate.

NOTE 4—Electrodes exhibiting stable passivity will behave as if the anodic reaction were diffusion limited, except that the passive current density is not affected by agitation.

5.3.3 It is possible to estimate b_a and b_c from the deviation from linearity of polarization curves in the 20–50 mV region around the corrosion potential. Several approaches have been proposed based on analyses of electrode kinetic models. See Refs **(9–11)** for more information.

5.3.4 In cases where the reaction mechanism is known in detail, the Tafel slopes may be estimated from the rate controlling step in the mechanism of the reaction. In general, Tafel slopes are given by **(12)**:

$$b = \frac{KRT}{nF} \qquad (9)$$

where:

K = a constant,

R = the perfect gas constant,

T = the absolute temperature,

n = the number of electrons involved in the reaction step, and

F = Faraday's constant.

At 25°C, $\left(\frac{RT}{2.303\ F}\right)$ is 59.2 mV/decade. For simple one electron reactions, K is usually found to be 2.0.

5.3.5 In cases where the Tafel slopes cannot be obtained from any of the methods described above, it may be necessary to determine the Stern-Geary constant experimentally by measuring mass loss and polarization resistance values.

5.4 The corrosion current density may be calculated from the polarization resistance and the Stern-Geary constant as follows:

$$i_{cor} = \frac{B}{R_p} \qquad (10)$$

The corrosion rate may then be calculated from the corrosion current, as described in Section 4. A sample calculation is given in Appendix X5.

5.5 There are several sources of errors in polarization resistance measurements:

5.5.1 Solution resistivity effects increase the apparent polarization resistance, whether measured by the potentiostatic or potentiodynamic methods **(13)**. The effect of solution resistance is a function of the cell geometry, but the following expression may be used to approximate its magnitude.

$$R_p = R_a - \rho l \qquad (11)$$

where:

R_a = the apparent polarization resistance, ohm cm^2,

ρ = the electrolyte resistivity in ohm cm,

l = the distance between the specimen electrode and the Luggin probe tip, or the reference electrode in cm, and

R_p = the true polarization resistance in ohm cm^2.

Significant solution resistivity effects cause the corrosion rate to be underestimated. A sample calculation is given in Appendix X6.

5.5.2 Potentiodynamic techniques introduce an additional error from capacitative charging effects. In this case, the magnitude of the error is proportional to scan rate. The error is illustrated by Eq (12):

$$I_{total} = I_f + c\left(\frac{dV}{dt}\right) \qquad (12)$$

where:

I_{total} = the cell current,

I_f = the Faradaic current associated with anodic and cathodic processes,

c = the electrode capacitance, and

dV/dt = the scan rate.

The capacitance charging effect will cause the calculated polarization resistance to be in error. Generally, this error is small with modest scan rates **(14)**.

5.5.3 Corroding electrodes may be the site for other electrochemical reactions. In cases where the corrosion potential is within 50 to 100 mV of the reversible potential of the corroding electrode, the electrochemical reactions will occur simultaneously on the electrode surface. This will cause either the anodic or cathodic b value to appear smaller than the corrosion reaction above. Consequently, the Stern-Geary constant B will be inflated and the predicted corrosion current will be overestimated **(15)**. In this case, the concentration of the corroding electrode ions is generally of the same magnitude or higher than other ions participating in the corrosion process in the electrolyte surrounding the electrode. Other redox couples that do not necessarily participate in the corrosion reaction may have similar effects. This is especially true for metals exhibiting passive behavior.

6. Keywords

6.1 corrosion current; corrosion rate; electrochemical; equivalent weight; polarization resistance; Tafel slopes

APPENDIXES

(Nonmandatory Information)

X1. SAMPLE CALCULATION—CORROSION CURRENT DENSITY

X1.1 *Data:*

X1.1.1 *Corrosion Current*—27.0 µA.

X1.1.2 *Specimen Size*—round anode area exposed.

X1.1.3 *Diameter*—1.30 cm.

X1.2 *Calculation*—See Eq (1) in text:

$$i_{cor} = \frac{27.0}{(1.30)^2 \frac{\pi}{4}} = \frac{27.0}{1.32} = 20.3\ \mu\text{A/cm}^2$$

X2. SAMPLE CALCULATION—ALLOY EQUIVALENT WEIGHT

X2.1 *Data:*

X2.1.1 *Alloy*—UNS S31600, actual composition not available.

X2.1.2 *Corrosion Potential*—300 mV versus SCE 1N sulfuric acid.

X2.2 *Assumptions:*

70

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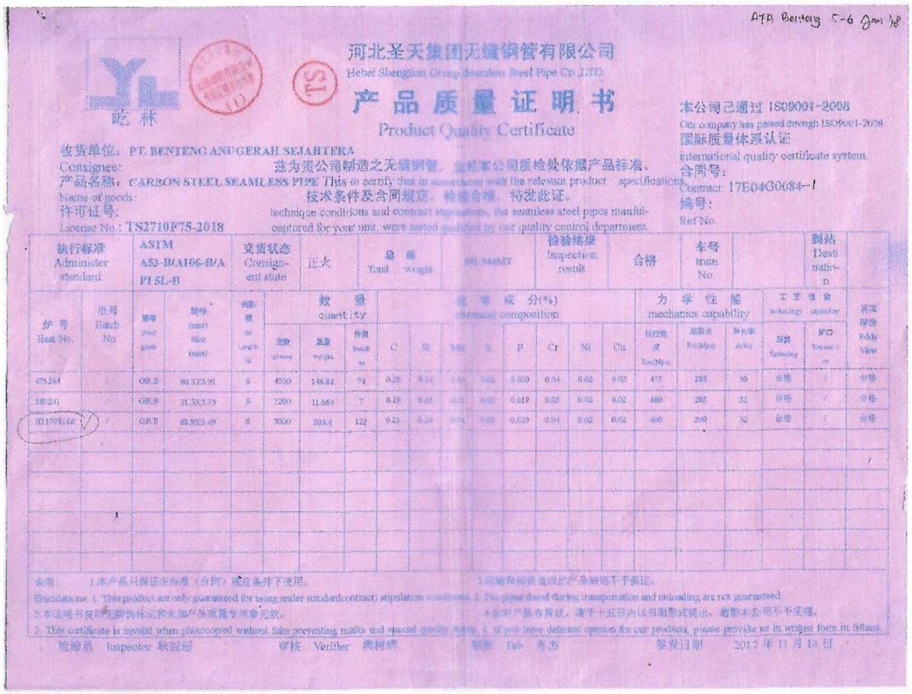

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合同号:
Contract 17E04G0084--1
编号:
Ref No.

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产品名称: CARBON STEEL SEAMLESS PIPE
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许可证号:
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This to certify that in accordance with the relevant product specifications, technique conditions and contract stipulations, the seamless steel pipes manufacptured for your unit, were tested qualified by our quality control department.

执行标准 Administer standard	ASTM A53-B/A106-B/API 5L-B	交货状态 Consignent state	正火	总重 Total weight	[illegible]MT	检验结果 Inspection result	合格	车号 train No.		到站 Destination	

<table>
<tr><th rowspan="2">炉号 Heat No.</th><th rowspan="2">批号 Batch No.</th><th rowspan="2">钢种 Steel grade</th><th rowspan="2">规格 (mm) Size (mm)</th><th rowspan="2">长度 Length</th><th colspan="3">数量 quantity</th><th colspan="9">化学成分(%) chemical composition</th><th colspan="3">力学性能 mechanics capability</th><th colspan="2">工艺性能 technology capability</th><th rowspan="2">涡流探伤 Eddy View</th></tr>
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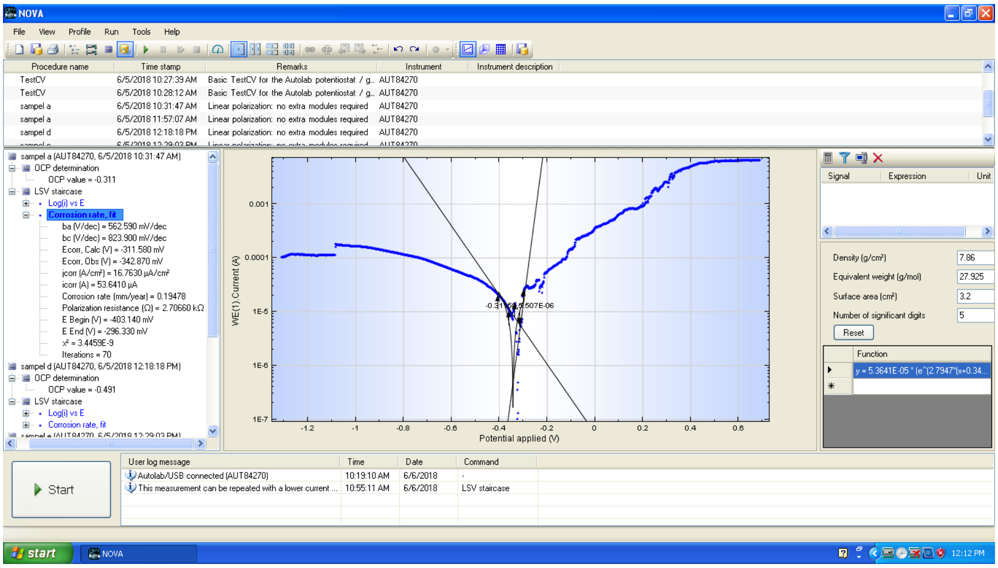

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TestCV	6/5/2018 10:28:12 AM	Basic TestCV for the Autolab potentiostat / g...	AUT84270	
sampel a	6/5/2018 10:31:47 AM	Linear polarization: no extra modules required	AUT84270	
sampel a	6/5/2018 11:57:07 AM	Linear polarization: no extra modules required	AUT84270	
sampel d	6/5/2018 12:18:18 PM	Linear polarization: no extra modules required	AUT84270	

- sampel a (AUT84270, 6/5/2018 10:31:47 AM)
  - OCP determination
    - OCP value = -0.311
  - LSV staircase
    - Log(i) vs E
    - Corrosion rate, fit
      - ba (V/dec) = 562.590 mV/dec
      - bc (V/dec) = 823.900 mV/dec
      - Ecorr, Calc (V) = -311.580 mV
      - Ecorr, Obs (V) = -342.870 mV
      - jcorr (A/cm²) = 16.7630 µA/cm²
      - icorr (A) = 53.6410 µA
      - Corrosion rate (mm/year) = 0.19478
      - Polarization resistance (Ω) = 2.70660 kΩ
      - E Begin (V) = -403.140 mV
      - E End (V) = -296.330 mV
      - χ² = 3.4459E-9
      - Iterations = 70
- sampel d (AUT84270, 6/5/2018 12:18:18 PM)
  - OCP determination
    - OCP value = -0.491
  - LSV staircase
    - Log(i) vs E
    - Corrosion rate, fit

Signal	Expression	Unit

Density (g/cm³) 7.86

Equivalent weight (g/mol) 27.925

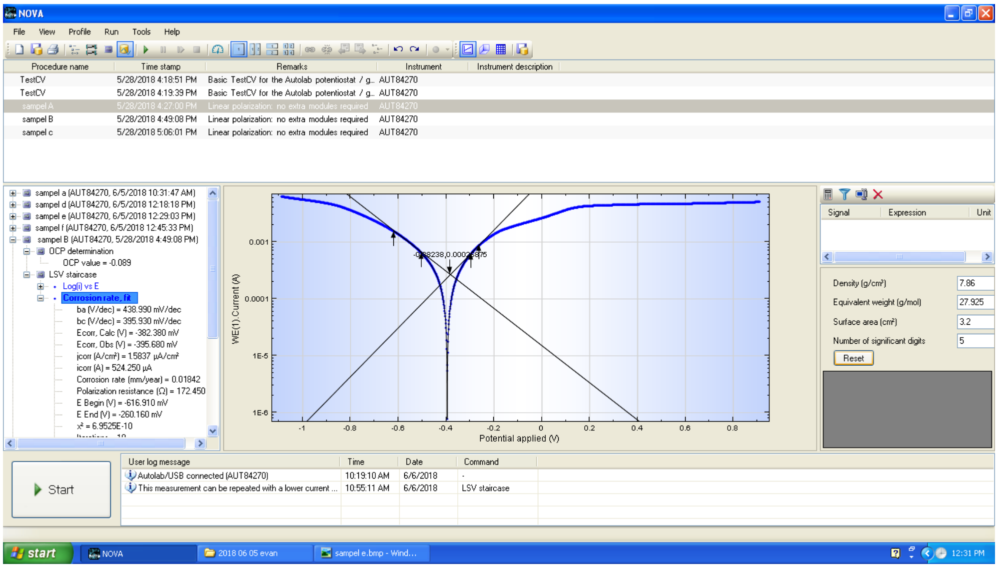
Surface area (cm²) 3.2

Number of significant digits 5

Reset

	Function
▶	y = 5.3641E-05 * (e^(2.7947*(x+0.34...
*	

User log message	Time	Date	Command
Autolab/USB connected (AUT84270)	10:19:10 AM	6/6/2018	-
This measurement can be repeated with a lower current ...	10:55:11 AM	6/6/2018	LSV staircase



Procedure name	Time stamp	Remarks	Instrument	Instrument description
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TestCV	5/28/2018 4:19:39 PM	Basic TestCV for the Autolab potentiostat / g...	AUT84270	
sampel A	5/28/2018 4:27:00 PM	Linear polarization: no extra modules required	AUT84270	
sampel B	5/28/2018 4:49:08 PM	Linear polarization: no extra modules required	AUT84270	
sampel c	5/28/2018 5:06:01 PM	Linear polarization: no extra modules required	AUT84270	

- sampel a (AUT84270, 6/5/2018 10:31:47 AM)
- sampel d (AUT84270, 6/5/2018 12:18:18 PM)
- sampel e (AUT84270, 6/5/2018 12:29:03 PM)
- sampel f (AUT84270, 6/5/2018 12:45:33 PM)
- sampel B (AUT84270, 5/28/2018 4:49:08 PM)
  - OCP determination
    - OCP value = -0.089
  - LSV staircase
    - Log(i) vs E
    - Corrosion rate, fit
      - ba (V/dec) = 438.990 mV/dec
      - bc (V/dec) = 395.930 mV/dec
      - Ecorr, Calc (V) = -382.380 mV
      - Ecorr, Obs (V) = -395.680 mV
      - jcorr (A/cm²) = 1.5837 µA/cm²
      - icorr (A) = 524.250 µA
      - Corrosion rate (mm/year) = 0.01842
      - Polarization resistance (Ω) = 172.450
      - E Begin (V) = -616.910 mV
      - E End (V) = -260.160 mV
      - χ² = 6.9525E-10

Density (g/cm³) 7.86
Equivalent weight (g/mol) 27.925
Surface area (cm²) 3.2
Number of significant digits 5
Reset

User log message	Time	Date	Command
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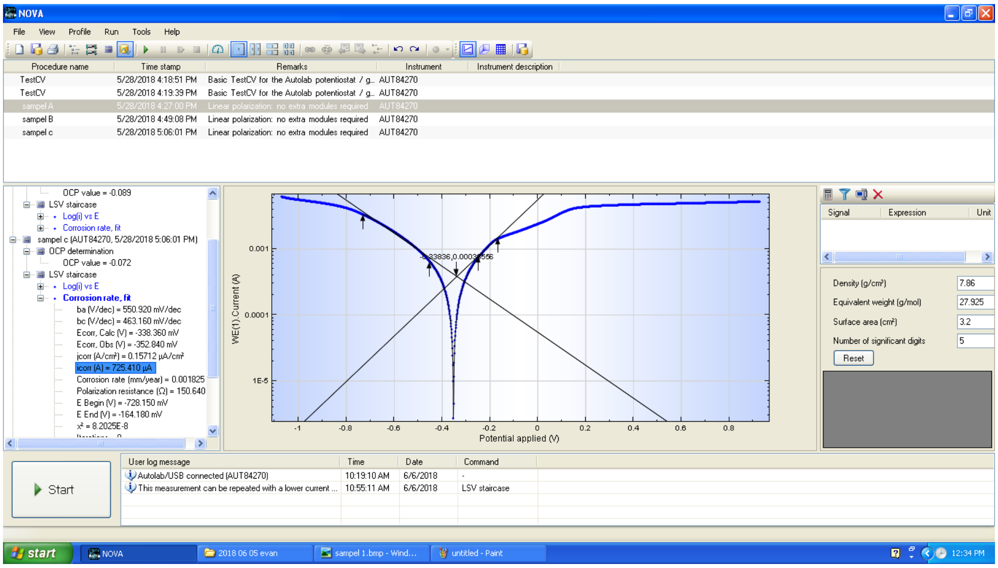

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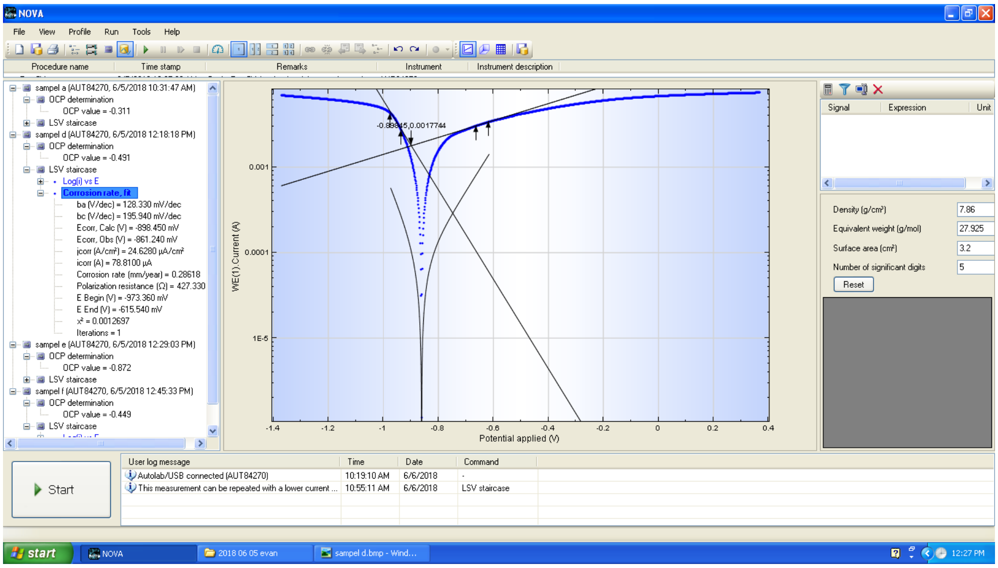
TestCV	5/28/2018 4:19:39 PM	Basic TestCV for the Autolab potentiostat / g...	AUT84270	
sampel A	5/28/2018 4:27:00 PM	Linear polarization: no extra modules required	AUT84270	
sampel B	5/28/2018 4:49:08 PM	Linear polarization: no extra modules required	AUT84270	
sampel c	5/28/2018 5:06:01 PM	Linear polarization: no extra modules required	AUT84270	

OCP value = -0.089
LSV staircase
Log(i) vs E
Corrosion rate, fit
sampel c (AUT84270, 5/28/2018 5:06:01 PM)
OCP determination
OCP value = -0.072
LSV staircase
Log(i) vs E
Corrosion rate, fit
ba (V/dec) = 550.920 mV/dec
bc (V/dec) = 463.160 mV/dec
Ecorr, Calc (V) = -338.360 mV
Ecorr, Obs (V) = -352.840 mV
jcorr (A/cm²) = 0.15712 µA/cm²
icorr (A) = 725.410 µA
Corrosion rate (mm/year) = 0.001825
Polarization resistance (Ω) = 150.640
E Begin (V) = -728.150 mV
E End (V) = -164.180 mV
x^2 = 8.2025E-8

Signal	Expression	Unit

Density (g/cm³) = 7.86
Equivalent weight (g/mol) = 27.925
Surface area (cm²) = 3.2
Number of significant digits = 5
Reset

User log message	Time	Date	Command
Autolab/USB connected (AUT84270)	10:19:10 AM	6/6/2018	-
This measurement can be repeated with a lower current ...	10:55:11 AM	6/6/2018	LSV staircase



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    OCP value = -0.311
  LSV staircase
sampel d (AUT84270, 6/5/2018 12:18:18 PM)
  OCP determination
    OCP value = -0.491
  LSV staircase
    Log(i) vs E
    Corrosion rate, fit
      ba (V/dec) = 128.330 mV/dec
      bc (V/dec) = 195.940 mV/dec
      Ecorr, Calc (V) = -898.450 mV
      Ecorr, Obs (V) = -861.240 mV
      jcorr (A/cm²) = 24.6280 µA/cm²
      icorr (A) = 78.8100 µA
      Corrosion rate (mm/year) = 0.28618
      Polarization resistance (Ω) = 427.330
      E Begin (V) = -973.360 mV
      E End (V) = -615.540 mV
      x^2 = 0.0012697
      Iterations = 1
sampel e (AUT84270, 6/5/2018 12:29:03 PM)
  OCP determination
    OCP value = -0.872
  LSV staircase
sampel f (AUT84270, 6/5/2018 12:45:33 PM)
  OCP determination
    OCP value = -0.449
  LSV staircase

Density (g/cm³): 7.86
Equivalent weight (g/mol): 27.925
Surface area (cm²): 3.2
Number of significant digits: 5

User log message	Time	Date	Command
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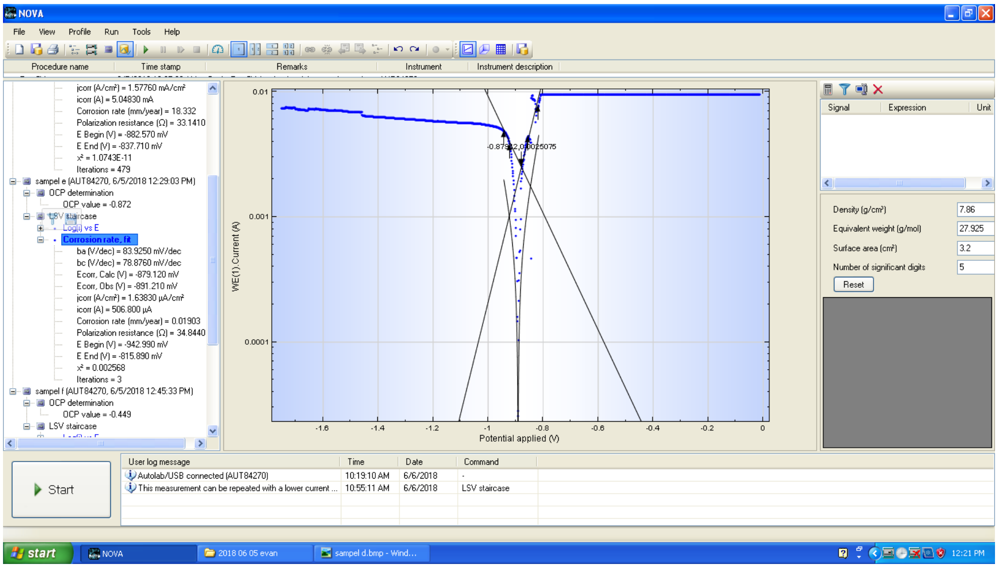
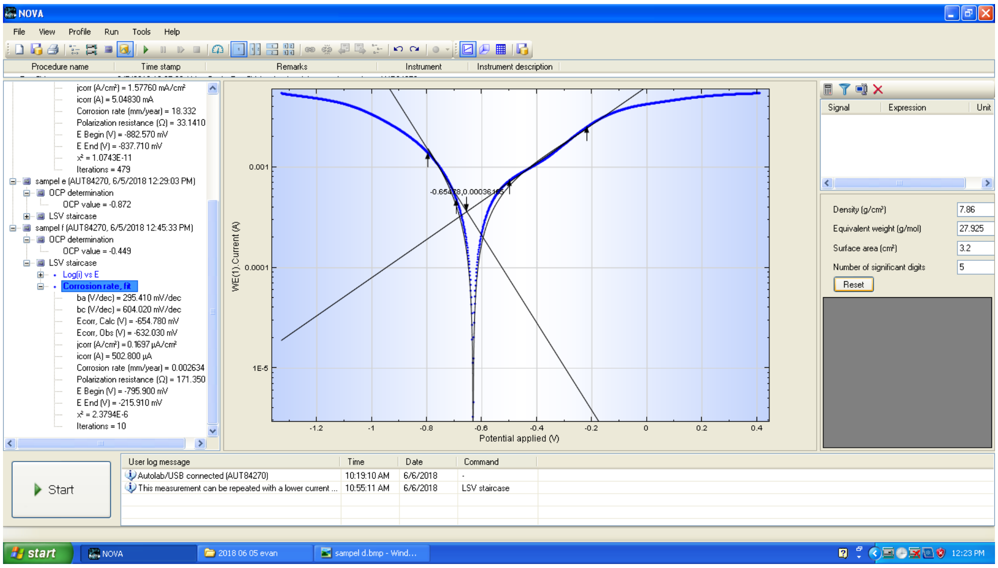


jcorr (A/cm²) = 1.57760 mA/cm²
icorr (A) = 5.04830 mA
Corrosion rate (mm/year) = 18.332
Polarization resistance (Ω) = 33.1410
E Begin (V) = -882.570 mV
E End (V) = -837.710 mV
χ² = 1.0743E-11
Iterations = 479
sampel e (AUT84270, 6/5/2018 12:29:03 PM)
  OCP determination
    OCP value = -0.872
  LSV staircase
    Log(i) vs E
    Corrosion rate, fit
      ba (V/dec) = 83.9250 mV/dec
      bc (V/dec) = 78.8760 mV/dec
      Ecorr, Calc (V) = -879.120 mV
      Ecorr, Obs (V) = -891.210 mV
      jcorr (A/cm²) = 1.63830 µA/cm²
      icorr (A) = 506.800 µA
      Corrosion rate (mm/year) = 0.01903
      Polarization resistance (Ω) = 34.8440
      E Begin (V) = -942.990 mV
      E End (V) = -815.890 mV
      χ² = 0.002568
      Iterations = 3
sampel f (AUT84270, 6/5/2018 12:45:33 PM)
  OCP determination
    OCP value = -0.449
  LSV staircase

Density (g/cm³) 7.86
Equivalent weight (g/mol) 27.925
Surface area (cm²) 3.2
Number of significant digits 5

User log message	Time	Date	Command
Autolab/USB connected (AUT84270)	10:19:10 AM	6/6/2018	-
This measurement can be repeated with a lower current ...	10:55:11 AM	6/6/2018	LSV staircase



jcorr (A/cm²) = 1.57760 mA/cm²
icorr (A) = 5.04830 mA
Corrosion rate (mm/year) = 18.332
Polarization resistance (Ω) = 33.1410
E Begin (V) = -882.570 mV
E End (V) = -837.710 mV
x² = 1.0743E-11
Iterations = 479
sampel e (AUT84270, 6/5/2018 12:29:03 PM)
OCP determination
OCP value = -0.872
LSV staircase
sampel f (AUT84270, 6/5/2018 12:45:33 PM)
OCP determination
OCP value = -0.449
LSV staircase
Log(i) vs E
Corrosion rate, fit
ba (V/dec) = 295.410 mV/dec
bc (V/dec) = 604.020 mV/dec
Ecorr, Calc (V) = -654.780 mV
Ecorr, Obs (V) = -632.030 mV
jcorr (A/cm²) = 0.1697 µA/cm²
icorr (A) = 502.800 µA
Corrosion rate (mm/year) = 0.002634
Polarization resistance (Ω) = 171.350
E Begin (V) = -795.900 mV
E End (V) = -215.910 mV
x² = 2.3794E-6
Iterations = 10

Density (g/cm³) 7.86
Equivalent weight (g/mol) 27.925
Surface area (cm²) 3.2
Number of significant digits 5

User log message	Time	Date	Command
Autolab/USB connected (AUT84270)	10:19:10 AM	6/6/2018	-
This measurement can be repeated with a lower current ...	10:55:11 AM	6/6/2018	LSV staircase

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The author was born on 31st August 1996 in Gresik, as the first child of 3 siblings. His father is Ir. Yoyok Setyono and his mother is Ir. Nurmaulitha Nuur. The author has completed the formal education in SD Al-Hikmah Surabaya, SMP Al-Hikmah Surabaya, and SMAN 21 Surabaya. The author continued his study for bachelor degree in Marine Engineering Double Degree (DDME) program of Institut Teknologi Sepuluh Nopember (ITS) and Hochshcule Wismar, with student id number: 04211441000034 and took area of expertise in Marine Machinery and System (MMS). The author was active in academic and non-academic activities including becoming the staff of Media and Information HIMASISKAL 2016/2017, head of Marine Videography and Photography (MVPC) committee of Marine Icon 2017, and becoming one of member in Marine Machinery and Systems (MMS) laboratory. The author has done on the job training in PT. PAL Surabaya (Persero) and PT. Badak NGL. The author can be contacted through revanandap96@gmail.com.