International Journal of Marine Engineering Innovation and Research, Vol. 8(3), Sept. 2023. 477-488
(pISSN: 2541-5972, eISSN: 2548-1479)

Corrosion Rate Estimation of Passenger Ships Ballast System Pipes

Moch Ricky Dariansyah[1], Mohammad Danil Arifin[2]

(Received: 20 August 2023 / Revised: 20 August 2023 /Accepted: 28 August 2023)

***Abstract*— Corrosion on ships is a common challenge that arises due to the exposure of various metal components to the marine environment. It is a natural electrochemical process that deteriorates the integrity and performance of the ship's structures and equipment over time. The corrosive agents in the marine environment include seawater, humidity, salt spray, chemicals, and microbiological organisms. Corrosion can affect different parts of a ship, such as the hull, ballast tanks, pipelines, propellers, rudders, and various metallic fittings. It can lead to the weakening of structural components, reduced operational efficiency, increased maintenance costs, and even safety hazards. Therefore, it is essential to determine the limitations of the lifespan and efficiency of pipes concerning the influence of corrosion. In this study, the corrosion rate of Galvanized Steel Pipe SCH 40 and Stainless Steel 304 was estimated. The corrosion rate of pipes was evaluated by variating the influence of 3% and 6% salinity and immersion time 240, 360, and 720 hours. The result shows that the corrosion rate tends to increase in higher salinity and immersion time.**

Keywords—*corrosion rate, ballast system pipes, galvanized steel, stainless steel*

I. INTRODUCTION

Metal is a broad category of materials that are typically solid, shiny, good conductors of electricity and heat, and can be shaped or molded. Metals have a wide range of applications in industries such as construction, manufacturing, electronics, and transportation [1][2].

On ships, metals are widely used in various structural components and equipment due to their strength, durability, and other desirable properties. However, the maritime environment presents a significant challenge for these metals, as they are constantly exposed to corrosive elements [3].

Ships operate in a corrosive marine environment that includes seawater, humidity, salt spray, and aggressive chemicals. These elements can initiate and accelerate corrosion processes on metal surfaces. It can lead to structural degradation, weakening of components, and reduced operational efficiency. It can cause leaks, decrease the lifespan of equipment, increase maintenance requirements, and potentially compromise the safety of the vessel and its crew.

A. Corrosion

Various types of corrosion can occur on ships, including general corrosion, localized corrosion i.e. pitting, crevice corrosion, galvanic corrosion, and stress corrosion cracking. Each type of corrosion manifests differently and affects different parts of the ship.

General corrosion is uniform corrosion that occurs over the entire exposed surface of a metal. It leads to a gradual loss of metal thickness and can weaken structural components. This type of corrosion is typically influenced by factors such as seawater chemistry, temperature, and oxygen concentration [3].

Pitting corrosion is defined as localized corrosion characterized by the formation of small pits or holes on the metal surface. It occurs in areas where the protective oxide layer is damaged or where crevices or other defects exist. Pitting corrosion can significantly reduce the strength of affected components [4].

In the case of galvanic corrosion, it occurs when two dissimilar metals are in electrical contact with each other in the presence of an electrolyte. The more active (less noble) metal corrodes while the less active (more noble) metal remains protected. This type of corrosion can occur in areas where different metals or alloys are nearby, such as fittings, fasteners, or welds [5].

However, stress corrosion cracking is defined as a form of corrosion that occurs under tensile stress in the presence of a corrosive environment. It can lead to sudden and catastrophic failure of components. SCC is influenced by factors such as material susceptibility, applied stress levels, and the presence of corrosive agents [6].

Corrosion on ships can occur due to various factors related to the marine environment and the materials used in ship construction. Some of the primary factors contributing to corrosion on ships can be described as follows [7]:

- Seawater: Seawater is a highly corrosive medium due to its high salt content, dissolved oxygen, and various impurities. The presence of chloride ions in seawater is particularly aggressive and can accelerate corrosion processes.
- Humidity and Moisture: High levels of humidity and moisture in the marine environment contribute to the corrosion of metal surfaces. Moisture can penetrate crevices, gaps, and coatings, creating an ideal environment for corrosion initiation and propagation.
- Dissolved Gases: Gases dissolved in seawater, such as oxygen and carbon dioxide, can play a significant role in corrosion. Oxygen concentration cells can

Moch Ricky Dariansyah, Department of Naval Architecture, Darma Persada University, Jakarta, 13450, Indonesia. E-mail: ricky.nautical@yahoo.com

Mohammad Danil Arifin, Department of Marine Engineering, Darma Persada University, Jakarta, 13450, Indonesia. E-mail: danilarifin.mohammad@gmail.com

form on metal surfaces, leading to localized corrosion, while carbon dioxide can contribute to the formation of acidic conditions that promote corrosion.

- Microbiological Activity: Marine environments harbor a variety of microbiological organisms, including bacteria, algae, and fungi. These organisms can attach to metal surfaces and create biofilms, which can accelerate corrosion processes through the production of corrosive byproducts and localized concentration cells.
- Coating and Paint Failure: Protective coatings and paints are commonly applied to ship surfaces to provide a barrier against corrosion occurrence. However, coating failures, such as cracking, delamination, or inadequate coverage, can expose underlying metals to corrosive agents, leading to accelerated corrosion.
- Design and Construction Factors: Design and construction aspects, such as improper material selection, inadequate corrosion protection measures, or structural design flaws, can contribute to localized corrosion, stress corrosion cracking, or crevice corrosion on ships.
- Galvanic Coupling: Ships often consist of different metals and alloys nearby, creating the potential for galvanic corrosion. When dissimilar metals are in contact, an electrochemical cell can form, leading to accelerated corrosion of the less noble (anodic) metal.

Ship operators and maintenance personnel need to understand these factors and implement effective corrosion prevention and control measures to ensure the longevity and integrity of the vessel.

Corrosion on ships can occur in various areas and components. Some common areas where corrosion is often observed on ships include as follows and illustrated in Figure 1:

- Hull: The hull is exposed to seawater, which makes it susceptible to corrosion. This includes the outer hull, bilge keels, and areas around waterlines.
- Ballast Tanks: Ballast tanks are used to control a ship's stability by adjusting its weight. These tanks can be prone to corrosion due to exposure to water and the presence of impurities.
- Pipelines and Piping Systems: Various pipelines and piping systems on ships, such as fuel lines, cooling systems, and ballast systems, can be vulnerable to corrosion, especially at joints, fittings, and areas where there are changes in flow or temperature.
- Propellers and Rudder Systems: Propellers and rudder systems are constantly exposed to seawater and are at risk of corrosion. Cavitation and galvanic corrosion can also affect these components.
- Decks and Superstructures: Decks, bulkheads, and superstructures are exposed to the marine environment and can experience corrosion, particularly in areas where water can accumulate or where dissimilar metals are in contact.
- Tankers and Cargo Hold: Cargo tanks in tankers and cargo hold in general cargo ships can be affected by corrosion due to the nature of the cargo they carry, such as chemicals, oils, or corrosive substances.

It's important to note that the specific areas and components prone to corrosion can vary depending on the type of ship, its operating conditions, maintenance practices, and the materials used.

In this study, we are focusing on the corrosion rate of passenger ships' ballast system pipes. Different types of pipes are used in ballast systems on ships, depending on various factors such as the specific application, ship design, and operating conditions. Here are some commonly used pipe materials for ballast systems on ships as illustrated in Figure 2.

- Carbon Steel Pipes: Carbon steel pipes are widely

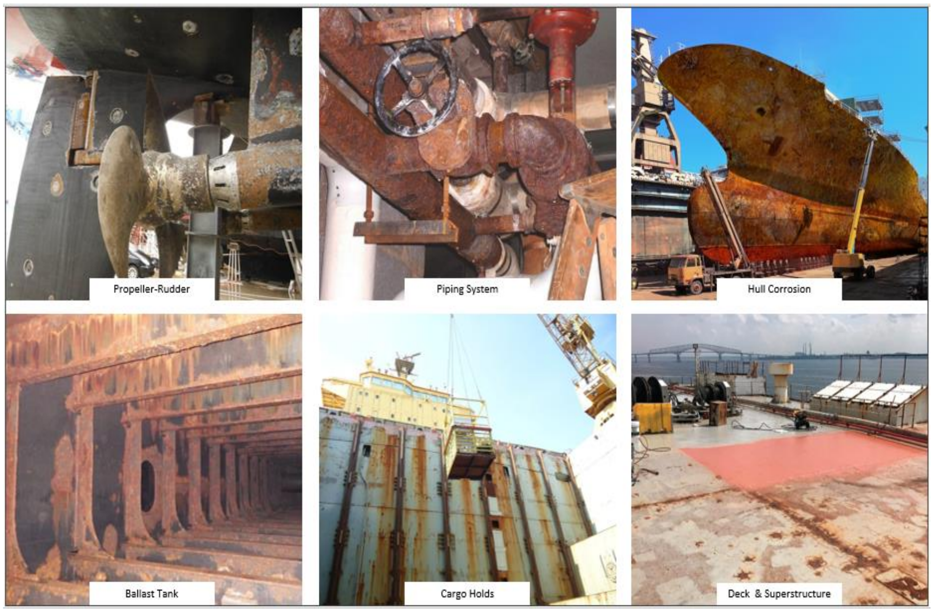

Figure. 1. Common areas of corrosions on ships

used in ballast systems due to their strength, durability, and cost-effectiveness. They are suitable for transporting seawater and are commonly used for ballast tanks, ballast lines, and associated piping.

- Stainless Steel Pipes: Stainless steel pipes are corrosion-resistant and offer better resistance to seawater and chemical corrosion compared to carbon steel. They are often used in ballast systems where there is a higher risk of corrosion or when specific regulations or vessel requirements demand corrosion-resistant materials.
- PVC (Polyvinyl Chloride) Pipes: PVC pipes are lightweight, affordable, and resistant to corrosion, making them suitable for certain applications in ballast systems. They are commonly used for smaller ballast lines, drainage systems, and non-critical components.
- Fiberglass Reinforced Plastic (FRP) Pipes: FRP pipes are lightweight, corrosion-resistant, and have high strength-to-weight ratios. They are used in specific applications where corrosion resistance and durability are essential, such as in corrosive environments or where weight reduction is desired.
- Copper-Nickel Alloy Pipes: Copper-nickel alloy pipes, specifically Cu-Ni 90/10 and Cu-Ni 70/30, are highly resistant to seawater corrosion. They are commonly used in shipbuilding for ballast systems and other applications where excellent resistance to corrosion and biofouling is required.

B. Corrosion Mechanism

Corrosion is a complex electrochemical process that occurs when metals or alloys react with their surrounding environment. The general mechanism of corrosion involves several steps [8]:

- Initiation: Corrosion typically starts with the initiation of a corrosion cell or a localized electrochemical reaction on the metal surface. Factors such as exposure to corrosive substances, the presence of impurities, or mechanical damage can initiate the corrosion process.
- Anodic Reaction: In the presence of an electrolyte (e.g., moisture, water, or a corrosive solution), the metal surface undergoes an oxidation reaction, known as the anodic reaction. This leads to the formation of metal ions and the release of electrons. For example, iron can oxidize to form ferrous ions (Fe^{2+}) in an aqueous environment. The anodic reaction is shown as the following process $Fe \rightarrow Fe^{2+} + 2e^-$.
- Cathodic Reaction: Simultaneously, a reduction reaction, known as the cathodic reaction, occurs in another region on the metal surface or a different metal. This reaction involves the consumption of electrons and often involves the reduction of oxygen or hydrogen ions. The oxygen reduction is shown by the following process $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$, and the hydrogen evolution defined as $2H^+ + 2e^- \rightarrow H_2$
- Ion Migration: The metal ions produced by the anodic reaction move away from the metal surface, typically through the electrolyte, due to the concentration gradient or fluid flow. This step is crucial for the continuation of the corrosion process.
- Electrolyte Diffusion: The electrolyte (such as water or moisture) continuously supplies ions and dissolved gases to the metal surface, sustaining the

Figure. 2. Common areas of corrosions on ships

electrochemical reactions and enabling the transfer of reactants and products.

- Corrosion Product Formation: As metal ions migrate away from the metal surface, they may react with other substances present in the environment to form corrosion products, such as rust, scales, or oxides. These products often have different physical properties and may provide some level of protection to the underlying metal.

II. METHOD

A. Weigh Loss Methods

The weight loss method was used as the method in this research. The weight loss method is a technique used to assess or measure the corrosion rate of a material. It involves subjecting a metal sample to a corrosive environment for a specific duration of time and then measuring the weight loss of the sample due to corrosion [9][10]. This method is widely used in corrosion research and provides valuable information on the corrosion behavior and rate of a material [11-13].

The corrosion rate may be calculated from the mass loss as follows [14-16]:

$$CR\ (mm/y) = \frac{w \times K}{\rho \times As \times T} \quad \text{..............................(1)}$$

Where:

- K is Constant
- T is the time of exposure, h,
- A is an area, cm^2
- W is mass loss, g, and
- D is defined as density, g/ cm^3 (D for steels and stainless steels -7.9 g/m^3, for copper 8.9 g/cm^3 for aluminum =2.7g/cm^3).
- K is 3.45 x 10^6 for a corrosion rate in mpy.
- Other constants include K= 8.76 x 10^4 for a corrosion rate in mm/y.

B. Experiment

For the experiment, the following steps should be conducted as follows:

- Preparing specimens
  - Cut 27 pieces of galvanized steel pipe SCH 40 and stainless steel 304 into dimensions of 30x40x4 mm each.
  - Ensure the specimens have a thickness of 4mm.
  - Validate the dimensions using a caliper to ensure accuracy.
- Testing procedures
  - Prepare a test solution by mixing distilled water with NaCl to achieve a salinity concentration of 3%, 6%, and 9% for each experiment.
  - Immerse the test specimens in the designated salinity levels for a specified immersion time t=240 hours, t=360 hours, and t=720 hours.
  - Clean the test specimens by immersing them in a solution of HF (20mL) and HNO_3 (100mL) mixed with 1000mL of water for SS 304 pipe material. For galvanized pipes, use a solution of NH_4OH (150mL) mixed with 1000mL of water.
  - Measure the weight of the test specimens using an analytical balance digital scale.
  - Capture surface images of the specimens using a 1000x microscope.

III. RESULTS AND DISCUSSION

By variating the experiment with the different salinity and flow velocities, the results of the corrosion rate between galvanized steel pipe SCH 40 and stainless steel 304 are shown as follows:

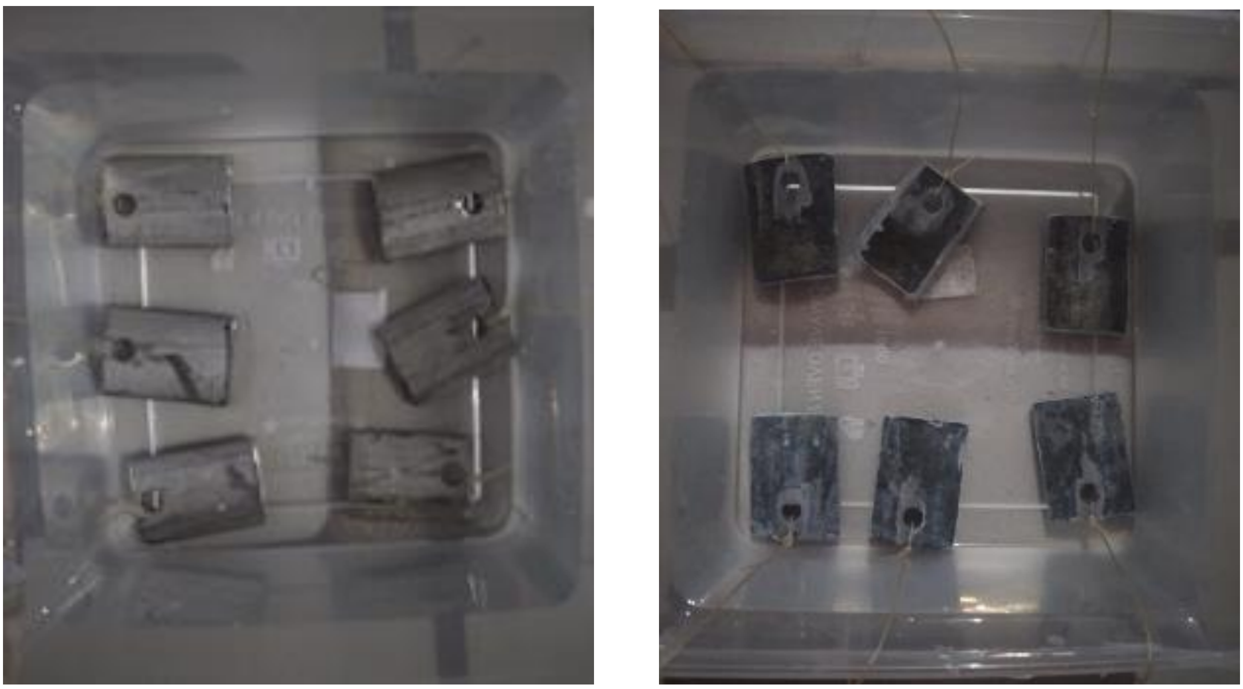

Figure. 3. Specimen immersion of galvanized steel pipe SCH 40 and stainless steel 304

A. Results of Corrosion Rate of t=240 hours with salinity 3%

Tables 1 and 2 below present the results of the corrosion rate calculation for SS 304 pipes and galvanized pipes after 240 hours of immersion in a NaCl solution with a salinity of 3%. The corrosion rate values obtained for SS 304 pipes are as follows: E1 = 0.039, E2 = 0.036, and E3 = 0.037 mm/y. Meanwhile, the corrosion rate values for galvanized steel pipes are H1 = 0.336, H2 = 0.339, and H3 = 0.344 mm/y. These values indicate that the corrosion rate of galvanized pipes is higher than that of SS 304 pipes. The difference in corrosion rate between SS 304 and galvanized pipes can be clearly shown by the comparison graph of the test specimens and corrosion rates in Figure 4.

B. Results of Corrosion Rate of t= 240 hours with salinity 0.6%

Tables 3 and 4 below present the results of the corrosion rate calculation for SS 304 pipes and

TABLE 1.
CORROSION RATE OF SS 304 WITH T=240 HOURS WITH SALINITY 3%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
E1	4.02	2.93	0.40	37.302	37.278	0.039
E2	4.04	3.00	0.40	37.749	37.726	0.036
E3	3.94	2.96	0.40	35.708	35.685	0.037
					Corrosion Rate Average	0.037

TABLE 2.
CORROSION RATE OF GALVANIZED PIPES WITH T=240 HOURS WITH SALINITY 3%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
H1	4.12	2.95	0.52	49.844	49.615	0.336
H2	4.03	2.97	0.52	49.495	49.268	0.339
H3	4.05	2.95	0.52	48.819	48.588	0.344
					Corrosion Rate Average	0.340

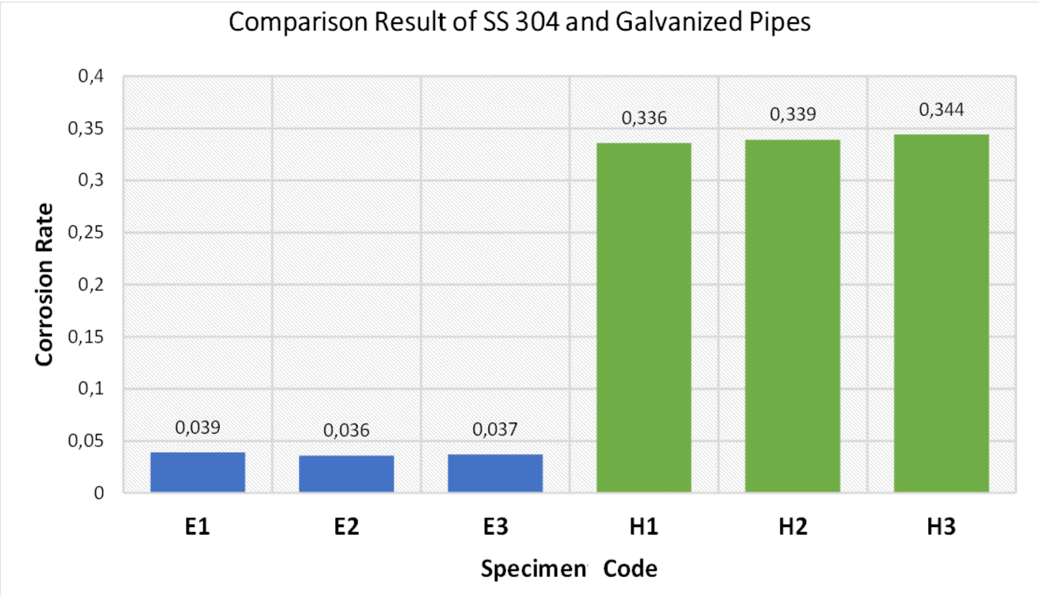

Figure. 4. Comparison of corrosion rate t=240 with salinity 3%

galvanized pipes after 240 hours of immersion in a NaCl solution with a salinity of 6%. The corrosion rate values obtained for SS 304 pipes are as follows: H1 = 0.048, H2 = 0.046, and H3 = 0.046 mm/y. Meanwhile, the corrosion rate values for galvanized steel pipes are D1 = 0.973, D2 = 0.922, and D3 = 0.923 mm/y. These values indicate that the corrosion rate of galvanized pipes is higher than that of SS 304 pipes.

The average corrosion rate values are presented, with galvanized pipes showing a corrosion rate of 0.939 mm/y (millimeters per year) and SS 304 pipes showing a corrosion rate of 0.047 mm/y. There is an increase in the corrosion rate between SS 304 and galvanized pipes due to a 6% increase in salinity during the same 240-hour immersion period.

TABLE 3.
CORROSION RATE OF SS 304 WITH T=240 HOURS WITH SALINITY 6%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
H1	3.99	2.99	0.4	36.316	36.286	0.048
H2	3.95	3.01	0.4	37.134	37.105	0.046
H3	4.09	3.01	0.4	37.610	37.580	0.046
				Corrosion Rate Average		0.047

TABLE 4.
CORROSION RATE OF GALVANIZED PIPES WITH T=240 HOURS WITH SALINITY 6%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
D1	4.04	2.99	0.52	49.225	48.565	0.973
D2	3.98	2.97	0.52	48.827	48.214	0.922
D3	4.17	2.94	0.52	49.524	48.890	0.923
				Corrosion Rate Average		0.939

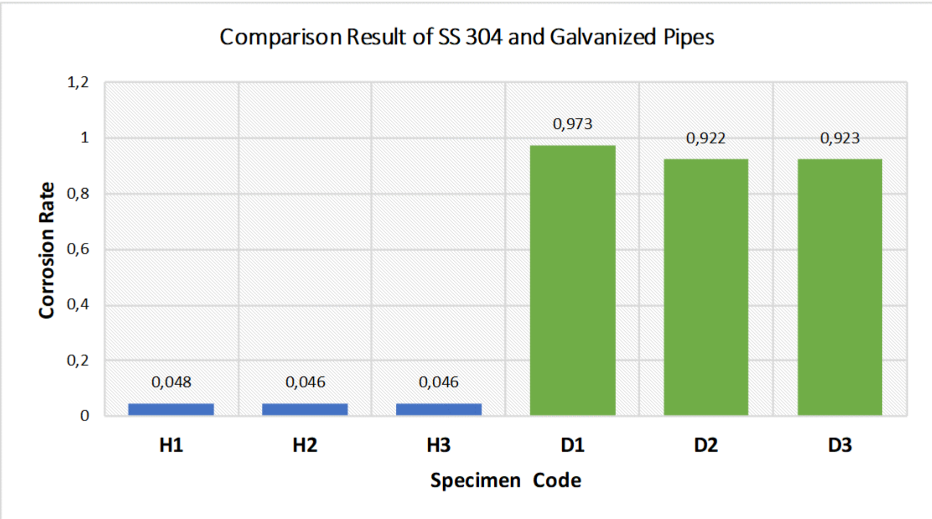

Figure. 5. Comparison of corrosion rate t=240 with salinity 6%

TABLE 5.
CORROSION RATE OF SS 304 WITH T=240 HOURS WITH SALINITY 9%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
A1	3.94	2.98	0.4	36.008	35.972	0.058
A2	3.94	2.9	0.4	35.791	35.755	0.059
A3	4.08	2.92	0.4	37.748	37.712	0.057
					Corrosion Rate Average	0.058

TABLE 6.
CORROSION RATE OF GALVANIZED PIPES WITH T=240 HOURS WITH SALINITY 9%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
C1	3.93	3.03	0.52	48.696	48.022	1.009
C2	4.03	2.93	0.52	49.004	48.308	1.048
C3	4.06	2.92	0.52	48.700	48.017	1.026
					Corrosion Rate Average	1.028

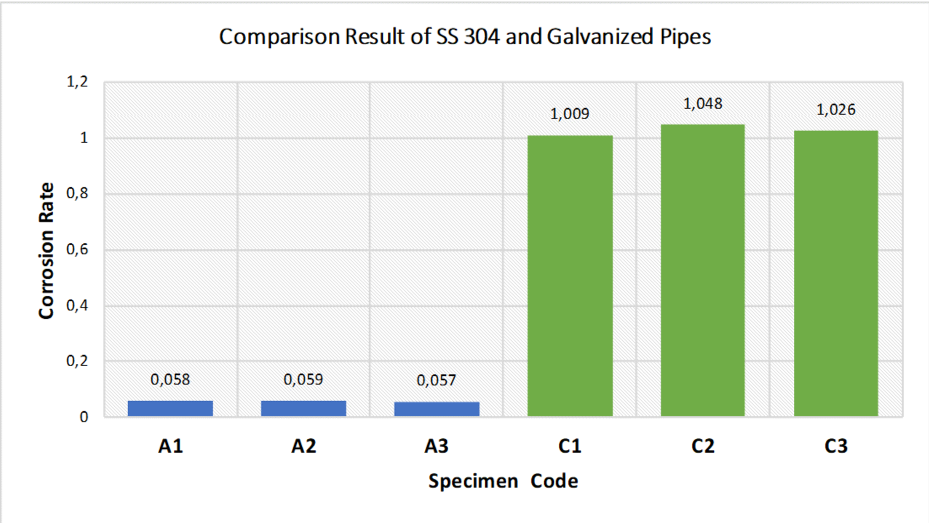

Figure. 6. Comparison of corrosion rate t=240 with salinity 9%

This demonstrates that increasing salinity leads to an increase in corrosion rate. The difference in corrosion rate between SS 304 and galvanized pipes can be clearly shown by the comparison graph of the test specimens and corrosion rates in Figure 5.

C. Results of Corrosion Rate of t=240 hours with salinity 9%

Table 5 and Table 6 below show the results of corrosion rate calculations for SS 304 pipes and galvanized pipes immersed in a NaCl solution with a salinity of 6% for 240 hours. The corrosion rate values obtained for each SS 304 pipe are A1 with a value of 0.058, A2 with a value of 0.059, and A3 with a value of 0.057. Meanwhile, the corrosion rate values for each galvanized steel pipe are C1 with a value of 1.009, C2 with a value of 1.048, and C3 with a value of 1.026. This indicates that the corrosion rate of galvanized pipes is greater than that of SS 304 pipes.

The difference in corrosion rates between SS 304 pipes and galvanized pipes can be clearly shown through the comparison graph of test specimens and corrosion rates in Figure 6. When comparing the corrosion rate values for NaCl solutions with salinities of 3%, 6%, and 9%, an increase in the corrosion rate is observed for both SS 304 and galvanized pipes during the same immersion time of 240 hours. This indicates that increasing salinity leads to an increase in the corrosion rate.

TABLE 7.
CORROSION RATE OF SS 304 WITH T=360 HOURS WITH SALINITY 3%

Specimen Code	Lenght (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
D1	3.98	2.91	0.4	36.352	36.313	0.042
D2	3.94	2.98	0.4	36.738	36.702	0.039
D3	4.00	2.93	0.4	37.023	36.990	0.035
					Corrosion Rate Average	0.039

TABLE 8.
CORROSION RATE OF GALVANIZED PIPES WITH T=360 HOURS WITH SALINITY 3%

Specimen Code	Lenght (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
B1	4.00	2.92	0.52	47.843	47.498	0.350
B2	4.09	3.04	0.52	48.797	48.452	0.331
B3	4.03	2.90	0.52	48.655	48.318	0.341
					Corrosion Rate Average	0.341

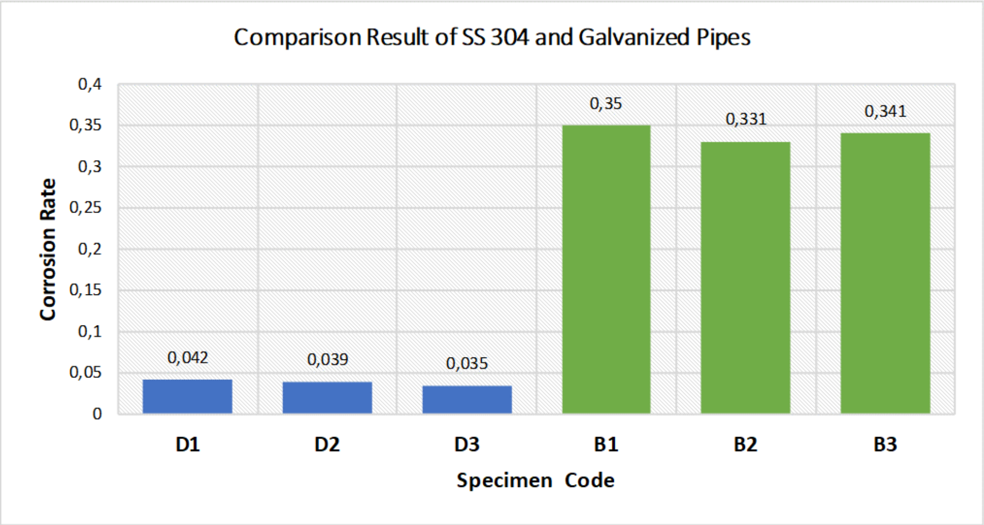

Figure. 7. Comparison of corrosion rate t=360 with salinity 3%

D. Results of Corrosion Rate of t=360 hours with salinity 3%

Table 7 and Table 8 below show the results of corrosion rate calculations for SS 304 pipes and galvanized pipes immersed in a NaCl solution with a salinity of 3% for 360 hours. The corrosion rate values obtained for each SS 304 pipe are D1 with a value of 0.042, D2 with a value of 0.039, and D3 with a value of 0.035. Meanwhile, the corrosion rate values for each galvanized steel pipe are B1 with a value of 0.350, B2 with a value of 0.331, and B3 with a value of 0.341. This indicates that the corrosion rate of galvanized pipes is greater than that of SS 304 pipes.

The difference in corrosion rates between SS 304 pipes and galvanized pipes can be clearly shown through the comparison graph of test specimens and corrosion rates in Figure 7. When comparing the results of corrosion rates for SS 304 and galvanized pipes during a 240-hour immersion in a 3% salinity NaCl solution, there is an increase in corrosion rate, though not significantly, and the results approach the corrosion rate of the 360-hour immersion.

E. Results of Corrosion Rate of t=360 hours with salinity 6%

Table 9 and Table 10 below show the results of corrosion rate calculations for SS 304 pipes and galvanized pipes immersed in a NaCl solution with a salinity of 6% for 360 hours. The corrosion rate values obtained for each SS 304 pipe are G1 with a value of 0.049, G2 with a value of 0.049, and G3 with a value of 0.048. Meanwhile, the corrosion rate values for each galvanized steel pipe are F1 with a value of 1.168, F2 with a value of 1.039, and F3 with a value of 1.087. This indicates that the corrosion rate of galvanized pipes is greater than that of SS 304 pipes. The difference in corrosion rates between SS 304 pipes and galvanized pipes can be clearly shown through the comparison graph of test specimens and corrosion rates in Figure 8. There is an increase in corrosion rate between SS 304 and galvanized pipes due to the 6% increase in salinity during the 360-hour immersion. In the comparison of corrosion rates for SS 304 and galvanized pipes during a 240-hour immersion in a 6% salinity NaCl solution, there is a slight increase in corrosion rate, but it is not very significant, and the results approach the corrosion rate of the 360-hour immersion.

F. Results of Corrosion Rate of t=720 hours with salinity 3%

Table 11 and Table 12 below show the results of corrosion rate calculations for SS 304 pipes and galvanized pipes immersed in a NaCl solution with a salinity of 3% for 720 hours. The corrosion rate values

TABLE 9.
CORROSION RATE OF SS 304 WITH T=360 HOURS WITH SALINITY 6%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
G1	4.00	2.91	0.40	35.852	35.807	0.049
G2	4.12	2.96	0.40	37.928	37.881	0.049
G3	4.04	2.95	0.40	38.065	38.020	0.048
					Corrosion Rate Average	0.049

TABLE 10.
CORROSION RATE OF GALVANIZED PIPES WITH T=360 HOURS WITH SALINITY 6%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
F1	4.00	2.97	0.52	49.161	47.993	1.168
F2	4.12	2.95	0.52	48.693	47.632	1.039
F3	4.05	2.92	0.52	48.736	47.652	1.087
					Corrosion Rate Average	1.098

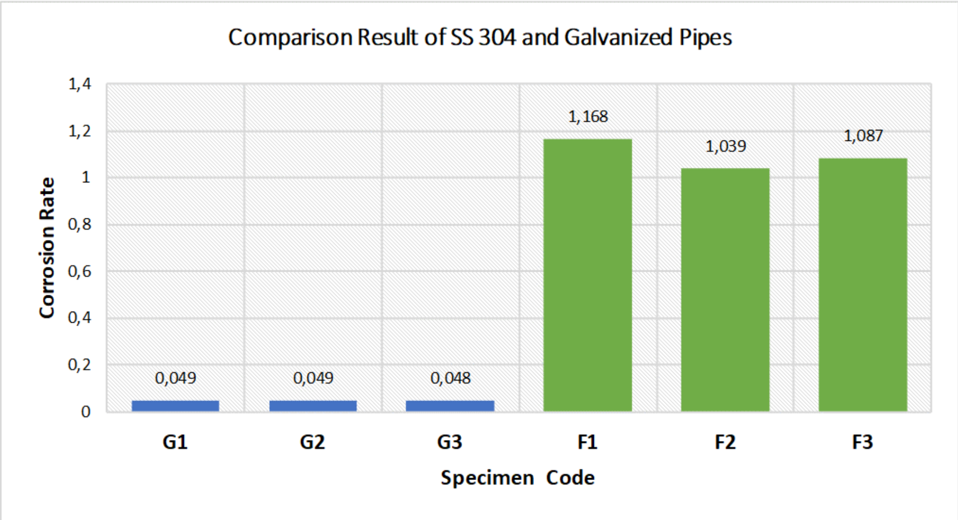

Figure. 8. Comparison of corrosion rate t=360 with salinity 6%

obtained for each SS 304 pipe are I1 with a value of 0.041, I2 with a value of 0.042, and I3 with a value of 0.041. Meanwhile, the corrosion rate values for each galvanized steel pipe are A1 with a value of 0.341, A2 with a value of 0.347, and A3 with a value of 0.349. This indicates that the corrosion rate of galvanized pipes is greater than that of SS 304 pipes.

The difference in corrosion rates between SS 304 pipes and galvanized pipes can be clearly shown through the comparison graph of test specimens and corrosion rates in Figure 9. There is a difference in corrosion rates between SS 304 and galvanized pipes during the 240-hour, 360-hour, and 720-hour immersion periods. When comparing the results of corrosion rates for SS 304 and galvanized pipes during the 240-hour and 360-hour immersions in a 3% salinity NaCl solution, there is a slight increase in corrosion rate, but it is not very significant, and the results approach the corrosion rate of the 720-hour immersion.

G. Results of Corrosion Rate of t=720 hours with salinity 6%

Table 13 and Table 14 below show the results of corrosion rate calculations for SS 304 pipes and galvanized pipes immersed in a NaCl solution with a salinity of 6% for 720 hours. The corrosion rate values obtained for each SS 304 pipe are F1 with a value of 0.050, F2 with a value of 0.050, and F3 with a value of 0.051. Meanwhile, the corrosion rate values for each galvanized steel pipe are E1 with a value of 1.182, E2 with a value of 1.172, and E3 with a value of 1.215. This indicates that the corrosion rate of galvanized pipes is

TABLE 11.
CORROSION RATE OF SS 304 WITH T=720 HOURS WITH SALINITY 3%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
I1	4.11	2.93	0.40	37.697	37.618	0.041
I2	4.01	3.05	0.40	37.990	37.909	0.042
I3	4.06	3.05	0.40	38.342	38.262	0.041
					Corrosion Rate Average	0.041

TABLE 12.
CORROSION RATE OF GALVANIZED PIPES WITH T=720 HOURS WITH SALINITY 3%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
A1	4.10	2.99	0.52	49.366	48.665	0.341
A2	4.10	2.90	0.52	48.979	48.283	0.347
A3	4.01	3.02	0.52	49.487	48.775	0.349
					Corrosion Rate Average	0.346

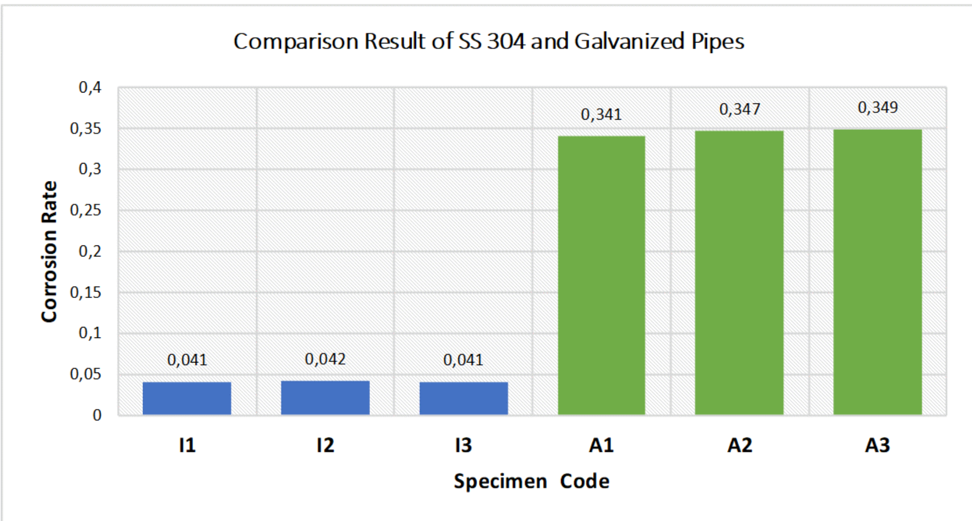

Figure. 9. Comparison of corrosion rate t=720 with salinity 3%

TABLE 13.
CORROSION RATE OF SS 304 WITH T=720 HOURS WITH SALINITY 6%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
F1	4.10	2.96	0.40	37.922	37.826	0.050
F2	4.05	2.91	0.40	36.986	36.893	0.050
F3	3.95	2.95	0.40	35.718	35.623	0.051
					Corrosion Rate Average	0.050

TABLE 14.
CORROSION RATE OF GALVANIZED PIPES WITH T=720 HOURS WITH SALINITY 6%

Specimen Code	Length (cm)	Wides (cm)	Thickness (cm)	Initial weight (gram)	Final weight (gram)	Corrosion Rate (mm/y)
E1	4.07	2.91	0.52	48.759	46.397	1.182
E2	4.06	2.98	0.52	49.119	46.733	1.172
E3	4.12	2.95	0.52	49.842	47.357	1.215
					Corrosion Rate Average	1.190

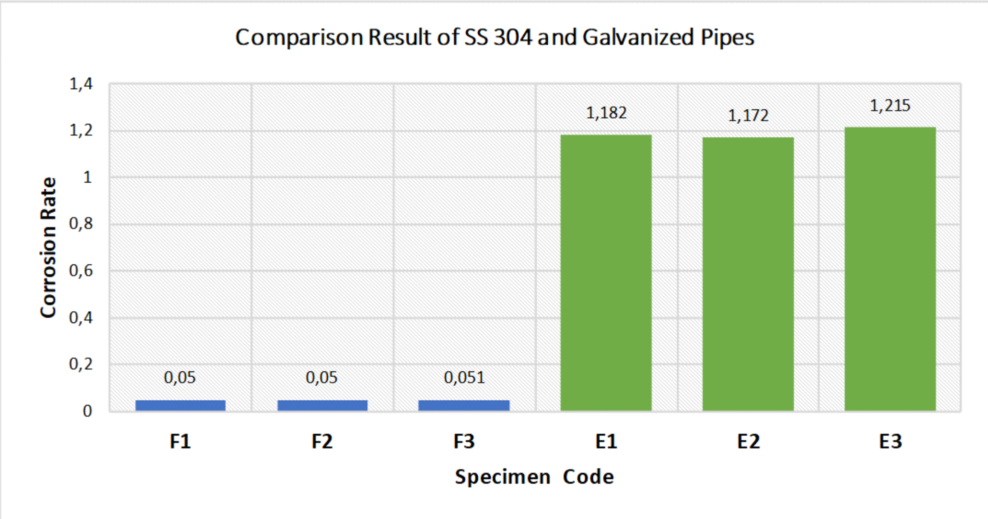

Figure. 10. Comparison of corrosion rate t=720 with salinity 6%

greater than that of SS 304 pipes.

The difference in corrosion rates between SS 304 pipes and galvanized pipes can be clearly shown through the comparison graph of test specimens and corrosion rates in Figure 10. There is a difference in corrosion rates between SS 304 and galvanized pipes during the 240-hour, 360-hour, and 720-hour immersion periods. When comparing the results of corrosion rates for SS 304 and galvanized pipes during the 240-hour, 360-hour, and 720-hour immersions in a 6% salinity NaCl solution, there is a slight increase in corrosion rate, but it is not very significant, and the results approach the corrosion rate of the 720-hour immersion. The same trend is observed when comparing the corrosion rates for SS 304 and galvanized pipes during the 240-hour, 360-hour, and 720-hour immersions in both 3% and 6% salinity NaCl solutions. This indicates that the corrosion rate is dependent on the level of salinity in the solution.

IV. CONCLUSION

Based on the conducted experiments, it can be observed that the corrosion rate in both SS 304 and galvanized pipes is influenced by the immersion duration and the percentage of salinity. The corrosion rate is directly proportional to the immersion time and the salinity percentage in the NaCl solution. The longer the immersion duration, the higher the corrosion rate. Similarly, as the salinity percentage increases, the corrosion rate tends to increase as well. When comparing the results of the corrosion rates between SS 304 and galvanized pipes, it can be concluded that SS 304 pipes are more suitable for ballast systems.

REFERENCES

[1] J. R. Davis. “Metals Handbook Desk Edition 2nd Edition”. ASM International Handbook Committee. 1998.

[2] Pierre R. Roberge. “Corrosion Engineering: Principles and Practice”. McGraw-Hill Education. 2008

[3] Luca Fedrizzi, Roger Francis. “Corrosion Control in the Maritime Industries”. Woodhead Publishing. 2013

[4] Christian Vargel. “Corrosion of Aluminium”. Elsevier. 2004

[5] Pierre R. Roberge. “Corrosion Basics: An Introduction”. NACE International. 2006.

[6] V.S. Raja. “Stress Corrosion Cracking: Theory and Practice”. Elsevier. 2011.

[7] Jeremy C. T. Carpentier, Adrian P. Mouritz. “Corrosion of Steel in Marine Environments”. CRC Press. 2021.

[8] Philip A. Schweitzer. “Fundamentals of Corrosion: Mechanisms, Causes, and Preventative Methods”. CRC Press. 2007.

[9] R. Winston Revie, Herbert H. Uhlig. “Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering”. Wiley. 2008.

[10] Pierre R. Roberge, Bernard R. Appleby. “Corrosion Testing Made Easy: Impedance & DC Techniques”. NACE International. 2017.

[11] Usman, Aminu D., Adams F. Victoria, and Linus N. Okoro. 2016. “Weight Loss Corrosion Study of Some Metals in Acid Medium”. JOURNAL OF ADVANCES IN CHEMISTRY 11 (2):3434-40. https://doi.org/10.24297/jac.v11i2.2211.

[12] V. R. Rathi, S. D. Nirmal, and S. J. Kokate. “Corrosion study of mild steel, tor steel, and CRS steel by weight loss method”. J. Chem. Pharm. Res., 2010, 2(2): 97-100.

[13] Malaret, F. (2022). Exact calculation of corrosion rates by the weight-loss method. Experimental Results, 3, E13. doi:10.1017/exp.2022.5.

[14] Raghuvir Singh.” Corrosion Evaluation and Monitoring Practices”. Industrial Corrosion: Evaluation & Mitigation. pp. 48-67.

[15] ASTM G I "Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

[16] Abdul Ghofur, Dhonie Adetya Rachman, Muhammad Mochtar Lutfi, and Fathur Rahman. “The Influence of Leachate Water on Corrosion Rate of Mild Steel Plate”. International Journal of Mechanical Engineering Technologies and Applications. Vol. 2 No. 2 (2021). https://doi.org/10.21776/MECHTA.2021.002.02.7