International Journal of Marine Engineering Innovation and Research, Vol. 8(3), Sept. 2023. 468-476
(pISSN: 2541-5972, eISSN: 2548-1479)

Lifespan Estimation of Galvanized Steel and Stainless Steel Pipe

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

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

***Abstract*— This research presents a comparative study focused on estimating the lifespan of galvanized steel pipes and stainless steel pipes within the context of a ballast system. Ballast systems play a crucial role in maintaining the stability and trim of vessels, making the longevity of the associated piping materials essential for maritime operations. This research aims to provide insights into the corrosion behavior and overall durability of galvanized steel and stainless steel pipes employed in ballast systems. The investigation involves an in-depth analysis of corrosion mechanisms specific to both galvanized steel and stainless steel pipes in the corrosive marine environment. The influence of factors such as salinity, and immersion time is examined. By understanding the distinct corrosion behavior of galvanized steel and stainless steel pipes, maritime industry stakeholders can make informed decisions regarding material selection, maintenance schedules, and potential retrofitting options. Ultimately, the insights gained from this study contribute to the sustainability and operational efficiency of maritime transport by enabling the optimization of ballast system infrastructure. As regulations and environmental considerations evolve, a comprehensive understanding of the lifespan estimation of galvanized steel and stainless steel pipes aids in mitigating potential failures, reducing downtime, and ensuring the safety and reliability of vessel operations. It is shown that the lifespan of stainless steel is longer than that of galvanized pipe.**

Keywords—*lifespan, corrosion rate, ballast system, galvanized steel pipe, stainless steel*

I. INTRODUCTION

The lifespan of piping refers to the period of time that a piping system, including the pipes and associated components, remains functional and operational before requiring replacement, repair, or maintenance due to factors such as wear, corrosion, and degradation [1-3]. Piping systems are used in various industries for transporting fluids, gases, and other materials, and their lifespan can vary based on several factors [4]:

- Material Selection:
  The type of material used for the pipes is a significant factor in determining lifespan. Different materials, such as steel, stainless steel, PVC, copper, and more, have varying levels of resistance to corrosion, mechanical stresses, and environmental conditions.
- Corrosion Resistance:
  Corrosion is a major factor that can affect the lifespan of pipes. Materials with good corrosion resistance, such as stainless steel or certain plastics, can have longer lifespans in corrosive environments.
- Operating Conditions:
  The conditions under which the piping system operates, including temperature, pressure, flow rate, and the types of fluids being transported, can impact the wear and degradation of the pipes.
- Environmental Factors:
  External factors such as exposure to sunlight, moisture, chemicals, and other environmental conditions can influence the rate of degradation of piping materials.
- Maintenance and Inspection:
  Regular maintenance, inspection, and cleaning of the piping system can extend its lifespan by identifying and addressing issues early.
- Design and Installation:
  Proper design and installation practices, including considerations for stress, expansion, contraction, and support, can impact the longevity of the piping system.
- Operational Stresses:
  Mechanical stresses from factors such as vibration, pressure fluctuations, and thermal expansion can contribute to material fatigue and impact the lifespan of the pipes.
- Fluid Characteristics:
  The nature of the fluid being transported, including its pH, corrosiveness, and potential for sediment buildup, can affect the rate of degradation of the piping material.
- Industry Standards:
  Compliance with industry standards and regulations related to materials, design, and installation can contribute to the overall lifespan of piping systems.
- Innovation and Advancements:
  Advancements in materials science and engineering can introduce new materials with improved properties that extend the lifespan of piping systems.

Lifespan estimations for piping materials can range from a few years to several decades, depending on the combination of those factors. Proper maintenance, routine inspection, and adherence to best practices in material selection and installation can contribute to maximizing the lifespan of piping systems and ensuring their safe and efficient operation. Moreover, an accurate estimation of lifespan helps ensure the safety, cost-

Mohammad Danil Arifin, Department of Marine Engineering, Darma Persada University, Jakarta, 13450, Indonesia. E-mail: danilarifin.mohammad@gmail.com
Moch Ricky Dariansyah, Department of Naval Architecture, Darma Persada University, Jakarta, 13450, Indonesia. E-mail: ricky.nautical@yahoo.com

effectiveness, and sustainable use of materials in various applications [5][6]. The lifespan of piping materials can vary widely based on factors. Here's an overview of the lifespan of common piping materials [7-8]:

- Carbon Steel Piping: Carbon steel is widely used due to its affordability and good mechanical properties. However, its lifespan can be influenced by corrosion, especially in corrosive environments. Proper coatings, linings, and cathodic protection can extend its lifespan. With proper maintenance, carbon steel pipes can last around 20 to 50 years or more.
- Stainless Steel Piping: Stainless steel offers excellent corrosion resistance due to its chromium content. Depending on the grade and environmental conditions, stainless steel pipes can have a lifespan ranging from 40 to 100+ years. Regular inspection and maintenance are important to ensure its longevity.
- Galvanized Steel Piping: Galvanized steel pipes are coated with a layer of zinc to protect against corrosion. The lifespan of galvanized pipes can be affected by the thickness and quality of the zinc coating, as well as environmental factors. They generally last around 20 to 50 years, but this can vary based on conditions.
- Copper Piping: Copper pipes have good corrosion resistance and are often used for plumbing systems. When properly installed and maintained, copper pipes can last for 50 to 70 years or more.
- PVC (Polyvinyl Chloride) Piping: PVC pipes are corrosion-resistant and lightweight, making them popular for various applications. Their lifespan can range from 25 to 100 years, depending on factors like sunlight exposure and temperature fluctuations.
- HDPE (High-Density Polyethylene) Piping: HDPE pipes are known for their durability and resistance to chemicals and environmental stress. Their lifespan can exceed 50 years, and they are often used for water and wastewater systems.
- Cast Iron Piping: Cast iron pipes were commonly used in the past, but their use has decreased due to corrosion concerns. Depending on the environment and maintenance practices, cast iron pipes may last around 50 to 100 years.
- Fiberglass Reinforced Plastic (FRP) Piping: FRP pipes are known for their corrosion resistance and durability. When properly designed and installed, they can have a lifespan exceeding 50 years.

It's important to note that the actual lifespan of piping materials can vary based on a combination of factors. Regular inspection, maintenance, and monitoring are essential to identifying signs of degradation and addressing potential issues before they fail. Additionally, advancements in material science and engineering continue to introduce new materials and technologies that may offer longer lifespans and improved performance in various applications.

A. Ballast System

A ship ballast system refers to the arrangement of tanks, compartments, and associated equipment onboard a vessel that allows for the controlled addition or removal of water or other fluids to adjust the ship's stability, buoyancy, and trim [9][10]. The primary purpose of a ballast system is to maintain the ship's equilibrium as cargo is loaded, unloaded, or redistributed throughout the voyage. Key components of a ship ballast system include:

1) Ballast Tanks: These are dedicated compartments within the ship's hull designed to hold water or other fluids. Ballast tanks are strategically located to distribute the added weight and control the ship's stability.
2) Piping Network: A network of pipes and valves connects the ballast tanks to facilitate the inflow and outflow of water. This system allows for precise control over the amount of ballast added or removed.
3) Pumps and Valves: Pumps are used to move water into or out of the ballast tanks, while valves regulate the flow rate. These components ensure that the ballast process is gradual and controlled.
4) Monitoring and Control System: Modern ballast systems are equipped with monitoring and control systems that provide real-time information about the ship's stability and trim. These systems often incorporate sensors, gauges, and automated controls to optimize ballast adjustments.
5) De-ballasting and Ballasting Operations: Ballast operations involve adding water to increase the ship's draft or removing water to decrease it. These operations are critical during cargo loading and unloading to maintain proper stability and to compensate for changes in weight distribution.
6) Environmental Considerations: With increasing environmental awareness, newer ballast systems focus on minimizing the transfer of invasive species and pollutants between different bodies of water. Ballast water treatment systems and compliance with international regulations are integral aspects of modern ballast system design.
7) Emergency Ballast Operations: In emergencies, such as flooding or damage to the vessel, ballast systems can be used to restore stability quickly. These systems are designed to respond rapidly to prevent further hazards.

The design and configuration of a ship's ballast system are influenced by various factors, including the ship's size, type, intended operations, trade routes, and regulatory requirements. The goal is to ensure the ship's safety, stability, and maneuverability under various conditions. Effective ballast systems contribute to the vessel's overall efficiency, cargo-handling capabilities, and navigational performance.

B. Ballast Process

The ballast process, often referred to as "ballasting," is a procedure used in maritime operations to adjust a ship's stability, buoyancy, and trim by adding or removing water or other fluids to specific compartments within the vessel's hull. Ballasting is essential for maintaining safe and efficient ship operations, particularly during cargo loading and unloading, as well as in various navigational and stability scenarios. The ballasting process typically involves the following steps:

1) Determining Ballast Requirements: The need for ballasting arises from changes in a ship's weight distribution due to cargo loading, unloading, or other factors. Naval architects and ship operators assess the ship's current condition to determine the amount of ballast required to achieve the desired stability and trim.
2) Identifying Ballast Tanks: Modern ships are equipped with dedicated ballast tanks strategically located throughout the hull. These tanks are designed to hold ballast water and are often divided into various compartments to optimize weight distribution.
3) Opening Valves: Valves connecting the ballast tanks to the sea are opened to allow seawater to enter the tanks. The water's entry point may be at the ship's bottom to maintain a lower center of gravity.
4) Filling Ballast Tanks: The selected ballast tanks are gradually filled with seawater. The water enters the tanks under the influence of gravity, and pumps may also be used to speed up the process.
5) Monitoring Stability and Trim: During the ballasting process, ship officers monitor the ship's stability and trim using onboard systems and instruments. The ship's stability is critical for safe navigation, and adjustments are made as necessary.
6) Distributing Ballast: The ballast water is distributed among different tanks to ensure even weight distribution and maintain the desired trim.
7) Securing Valves: Once the desired stability and trim are achieved, the valves connecting the ballast tanks to the sea are closed to prevent further water intake.
8) Navigating and Maneuvering: The ship continues its voyage with adjusted stability and trim. Properly ballasted ships are easier to maneuver, experience less roll, and maintain optimal performance.
9) De-ballasting: At the destination port or when the ship's cargo is unloaded, ballast water may need to be removed to restore the ship's original draft and balance. The de-ballasting process is essentially the reverse of ballasting, where water is pumped out of the ballast tanks.

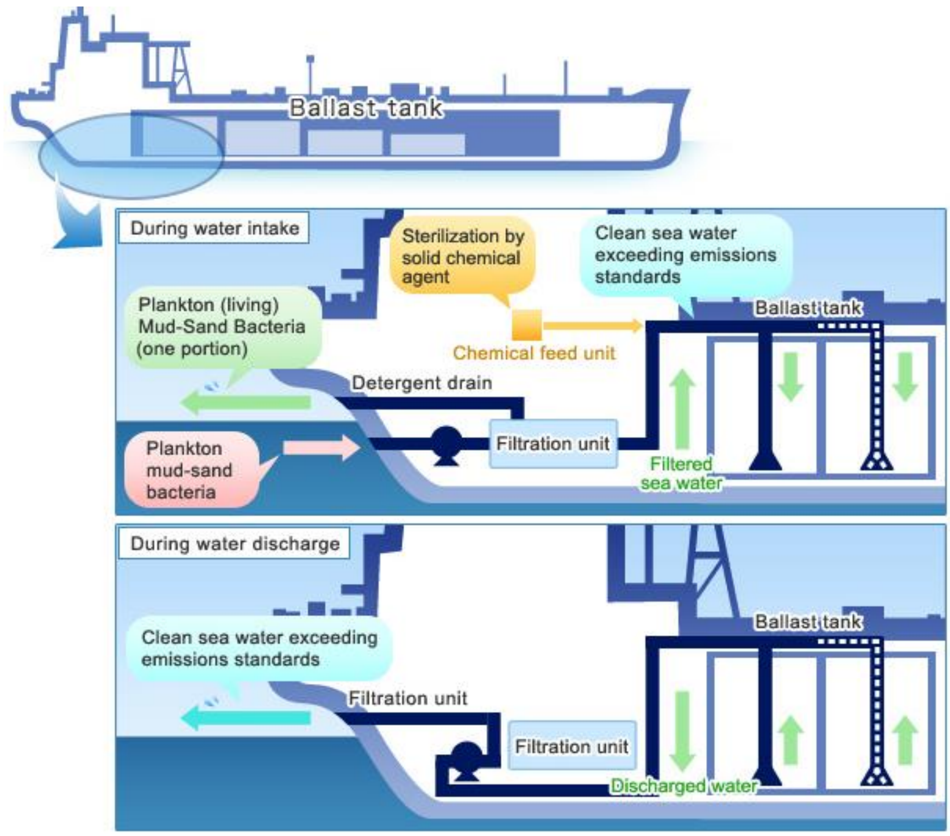


Figure.1. Diagram of ballast water management

It's important to note that in recent years, regulations like the Ballast Water Management Convention (BWMC) have been introduced to address the environmental impact of ballast water discharge, aiming to prevent the spread of invasive species. Ships are now required to meet specific standards and adopt proper ballast water treatment methods before discharging ballast water into new locations.

C. Salinity and Lifespan

The salinity of seawater can have a significant impact on the lifespan of ballast system piping. Salinity refers to the concentration of dissolved salts in seawater and is typically measured in parts per thousand (ppt) or practical salinity units (PSU). The higher the salinity, the more corrosive the seawater can be due to the presence of various ions, particularly chloride ions. This corrosion potential can influence the degradation rate of piping materials and consequently affect their lifespan. Therefore, the characteristics of seawater that can influence the lifespan of the piping system should be understood as follows:

1) Corrosion Potential: Seawater contains various ions, including chloride ions, which can accelerate the corrosion of metals used in piping systems. The corrosion potential of seawater influences material choices for ballast piping, favoring materials that are resistant to the corrosive effects of chloride ions.
2) Temperature: Seawater temperature can vary based on location and depth. Temperature fluctuations can affect the thermal expansion and contraction of piping materials, requiring design considerations to prevent stress-induced failures.
3) Oxygen Content: Seawater contains dissolved oxygen, which can contribute to the corrosion of metal pipes through processes like oxygen concentration cell corrosion. This is another factor that impacts material selection and maintenance strategies.
4) Suspended Solids: Seawater may contain suspended solids, including sediments and particles. These solids can potentially cause abrasion and erosion of piping materials, affecting their lifespan and efficiency.
5) Biofouling and Microorganisms: Seawater can harbor microorganisms and marine organisms that can attach to and grow on the inner surfaces of pipes. Biofouling can reduce flow rates, increase pressure drop, and even lead to microbiologically influenced corrosion (MIC), necessitating regular maintenance and potentially affecting piping lifespan.
6) Scale Formation: Seawater can contain minerals that, under certain conditions, may precipitate and form mineral scale deposits on the inner surfaces of pipes. These deposits can reduce flow efficiency and impact the piping system's performance.
7) Chemical Composition: Seawater can contain various dissolved chemicals and ions that can interact with piping materials. Compatibility with the chemical composition of seawater is an important consideration in material selection.

II. METHOD

The method used to predict the piping system lifetime is divided into two (2) steps: (1) calculate the corrosion rate; (2) calculate the lifespan. The detailed steps are described as follows:

A. Corrosion Rate

Corrosion rate refers to the speed or rate at which a material undergoes corrosion, which is the process of deterioration and degradation of a material due to chemical reactions with its environment [11]. Corrosion can occur when metals or other materials come into contact with corrosive substances, such as oxygen, water, acids, or salts, leading to the gradual breakdown of the material's structure.

The corrosion rate is typically measured in units of mass loss per unit area per unit of time (e.g., millimeters per year or inches per year) [12]. It indicates how quickly a material is being corroded and can be influenced by various factors, including the type of material, environmental conditions, temperature, humidity, pH, and the presence of pollutants or aggressive chemicals.

- Corrosion Mechanism

The corrosion mechanism involves an electrochemical process that occurs at the microscopic level on the surface of a metal material [13]. Here's a simplified representation of the corrosion mechanism using the example of iron:

1) Anodic Reaction (Oxidation): At the anode site on the metal surface, metal atoms lose electrons, becoming positively charged ions (cations). In the case of iron, iron atoms release electrons to become iron ions (Fe^{2+}):
$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$$
2) Cathodic Reaction (Reduction): In the surrounding electrolyte (such as water with dissolved oxygen), a cathode site forms where reduction reactions occur. Oxygen molecules from the air and water molecules combine to form hydroxide ions (OH^-):
$$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$$
3) Overall Electrochemical Reaction: The anodic and cathodic reactions are part of an electrochemical cell. Electrons released at the anode travel through the metal to the cathode, completing the circuit. The overall reaction combines the anodic and cathodic reactions:
$$Fe(s) + O_2(g) + 2H_2O(l) \rightarrow Fe^{2+}(aq) + 4OH^-(aq)$$
4) Formation of Corrosion Products: The iron ions (Fe^{2+}) generated at the anode combine with hydroxide ions (OH^-) from the cathodic reaction to form iron hydroxide ($Fe(OH)_2$):
$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$$
5) Oxidation of Iron Hydroxide to Rust: Iron hydroxide is further oxidized by oxygen from the environment

to form hydrated iron (III) oxide, commonly known as rust:

$$4Fe(OH)_2(s) + O_2(g) \rightarrow 2Fe_2O_3 \cdot 3H_2O(s)$$

This mechanism demonstrates how the transfer of electrons and ions between the anodic and cathodic sites drives the corrosion process. The anodic site experiences oxidation as metal atoms loses electrons, while the cathodic site undergoes reduction as oxygen accepts electrons. The overall electrochemical reaction results in the formation of corrosion products like rust.

- Corrosion Rate Calculation

Calculating corrosion rate involves determining the rate at which a material is corroding, typically measured in units of mass loss per unit area per unit of time (e.g., millimeters per year or inches per year). Several methods can be used to calculate corrosion rate, each tailored to specific scenarios and available data. In this study, the corrosion rate is calculated by using the Weight Loss Method based on Standards Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimen, American Society for Testing Material (ASTM G1-03).

The Weight Loss Method is a simple and widely used technique to calculate the corrosion rate of a material by measuring the change in weight of a sample before and after exposure to a corrosive environment. This method is suitable for scenarios where the material's weight loss due to corrosion is easily measurable. The Weight Loss Method stage is shown as follows:

1) Sample Preparation: A representative sample of the material is selected and cleaned to remove any contaminants or impurities that could affect the measurement. The sample is accurately weighed using a balance.
2) Exposure: The sample is exposed to a corrosive environment for a specific period of time. This environment could be a solution, gas, or any medium known to cause corrosion of the material.
3) Cleaning and Weighing: After the exposure period, the sample is carefully removed, cleaned to remove any corrosion products, and dried to prevent any residual moisture from affecting the measurement. The sample is then reweighed using the same balance.
4) Calculation of Corrosion Rate: The corrosion rate can be calculated using the following formula [14]:

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

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. Lifespan Calculation

API 570 is a widely used standard published by the American Petroleum Institute (API) that provides guidelines for the inspection, repair, alteration, and rerating of in-service piping systems. It includes a methodology for calculating the remaining life of piping components based on their condition, material properties, and operating history. The remaining life calculation helps determine when a piping component will need repair, replacement, or continued operation.

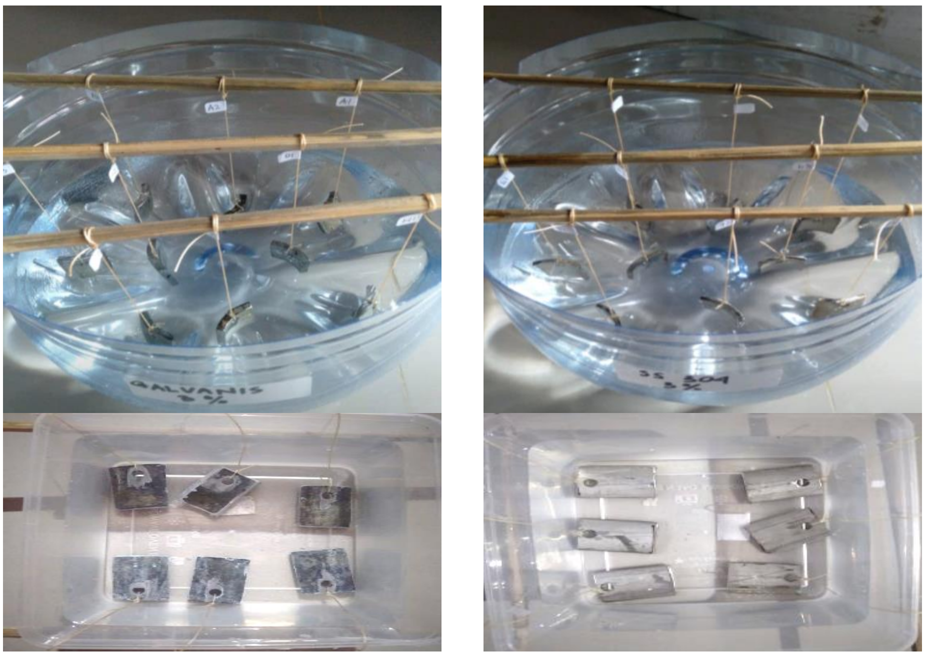


Figure. 2. Specimen immersion of galvanized steel pipe SCH 40 and stainless steel 304

TABLE 1.
INITIAL WEIGHT OF SPECIMEN

No	Galvanized Steel Pipe SCH 40		No	Stainless Steel 304	
	Specimen Code	Weight of Specimen (gr)		Specimen Code	Weight of Specimen (gr)
1	A1	49.366	1	A1	36008
2	A2	48.979	2	A2	35791
3	A3	49.487	3	A3	37748
4	B1	47.843	4	B1	36168
5	B2	48.797	5	B2	36295
6	B3	48.655	6	B3	37337
7	C1	48.696	7	C1	37381
8	C2	49.004	8	C2	35764
9	C3	48.700	9	C3	37582
10	D1	49.225	10	D1	36352
11	D2	48.827	11	D2	36738
12	D3	49.524	12	D3	37023
13	E1	48.759	13	E1	37302
14	E2	49.119	14	E2	37749
15	E3	49.842	15	E3	35708
16	F1	49.161	16	F1	37922
17	F2	48.693	17	F2	36986
18	F3	48.736	18	F3	35718
19	G1	48.505	19	G1	35852
20	G2	49.098	20	G2	37928
21	G3	49.778	21	G3	38065
22	H1	49.844	22	H1	36316
23	H2	49.495	23	H2	37134
24	H3	48.819	24	H3	37610
25	I1	49.760	25	I1	37697
26	I2	48.234	26	I2	37990
27	I3	49.727	27	I3	38342

API 570 provides guidelines for calculating the lifespan or remaining life of a piping component based on the minimum thickness required for the intended service condition, the current thickness, and the corrosion rate. The formula is shown as follows [15]:

$$t_r = \frac{tacc - treq}{Cr} \quad \text{......................................(2)}$$

Where:
- t_r is remaining life (years)
- tacc defined as a thickness actual (mm)
- Cr is corrosion Rate (mm/y)

C. Experiment

For the experiment, the following steps should be conducted as follows: (1) Cut 27 pieces of galvanized steel pipe SCH 40 and stainless steel 304 into dimensions of 30x40x4 mm each; (2) Ensure the specimens have a thickness of 4mm; and (3) Validate the dimensions using a caliper to ensure accuracy. The illustration of the experiment is shown in Figure 2, and the initial weight of the specimen is shown in Table 1.

III. RESULTS AND DISCUSSION

A. The Lifespan of Galvanized Steel Pipe SCH 40 with 3% and 6% Salinity

From Tables 2 and 3 below, the lifespan of galvanized pipes with salinity levels of 3% and 6% without flow velocity was obtained. These results were calculated using the API 570 formula by first determining the corrosion rate of the galvanized pipes. The factors influencing the lifespan of the pipes are the thickness of the galvanized pipes, the corrosion rate of the galvanized pipes, and the pipe thickness allowed by the classification society. In this study, the classification society parameter used is BKI Volume 3 Chapter 11.

The obtained lifespan value for galvanized pipes with a salinity level of 3% is 11.799 years, and the lifespan value for galvanized pipes with a salinity level of 6% is 2.954 years. When comparing the lifespan values of galvanized pipes with salinity levels of 3% and 6%, the lifespan value of galvanized pipes with a salinity level of 6% is smaller.

B. The Lifespan of Stainless-Steel 304 Pipe with 3% and 6% Salinity

It can be seen that the lifespan value for SS 304 pipes with a salinity level of 3% is 76.923 years, and the lifespan value for SS 304 pipes with a salinity level of 6% is 61.224 years as shown in Tables 4 and 5 below. When comparing the lifespan values of SS 304 pipes with salinity levels of 3% and 6%, the lifespan value of SS 304 pipes with a salinity level of 6% is smaller. This indicates that the concentration of salinity in the NaCl solution affects the lifespan value of the pipes. The higher the salinity value of the NaCl solution, the smaller the lifespan value of the pipes. Compared to the galvanized steel pipe, the lifespan value of the stainless-steel pipe is longer for both salinity levels of 3% and 6%.

C. The Lifespan of Galvanized Steel and Stainless-Steel Pipe with 3% and a Flow Velocity of 6.83 m/s

As shown in Table 6 below, the lifespan value for SS 304 pipes with a salinity level of 3% and a flow velocity of 6.83 m/s is 65.217 years, lifespan value for galvanized is 5.571 years. When compared to the result of the lifespan of SS 304 pipes with a salinity level of 3% without flow velocity, the lifespan value of SS 304 pipes with a flow velocity of 6.83 m/s is smaller.

D. The Lifespan of Galvanized Steel and Stainless-Steel Pipe with 3% and a Flow Velocity of 3.45 m/s

From Table 7 below, the lifespan of SS 304 pipes and galvanized pipes with a salinity level of 3% and a flow velocity of 3.45 m/s was obtained.

The obtained lifespan value for SS 304 pipes is 71.428 years, and the obtained lifespan value for galvanized pipes with a salinity level of 3% and a flow velocity of 3.45 m/s is 7.092 years.

Compared to the result of the lifespan of SS 304 pipes with a salinity level of 3% without flow velocity, the lifespan value of SS 304 pipes with a salinity level of 3% and a flow velocity of 3.45 m/s is smaller. However, when compared to the lifespan value of SS 304 pipes with a salinity level of 3% and a flow velocity of 6.83 m/s, the lifespan value of SS 304 pipes with a salinity level of 3% and a flow velocity of 3.45 m/s is larger. The same pattern is observed in the results for galvanized pipes.

TABLE 2.
LIFESPAN PREDICTION OF GALVANIZED STEEL WITH SALINITY 3%

Immersion Time (hours)	Corrosion Rate	Salinity	Average Corrosion Rate	Lifespan Prediction (Year)
240	0.339	3%		
360	0.341	3%	0.342	11.79
720	0.346	3%		

TABLE 3.
LIFESPAN PREDICTION OF GALVANIZED STEEL WITH SALINITY 6%

Immersion Time (hours)	Corrosion Rate	Salinity	Average Corrosion Rate	Lifespan Prediction (Year)
240	1.487	6%		
360	1.375	6%	1.354	2.954
720	1.202	6%		

TABLE 4.
LIFESPAN PREDICTION OF STAINLESS STEEL WITH SALINITY 3%

Immersion Time (hours)	Corrosion Rate	Salinity	Average Corrosion Rate	Lifespan Prediction (Year)
240	0.037	3%		
360	0.039	3%	0.039	76.92
720	0.041	3%		

TABLE 5.
LIFESPAN PREDICTION OF STAINLESS STEEL WITH SALINITY 6%

Immersion Time (hours)	Corrosion Rate	Salinity	Average Corrosion Rate	Lifespan Prediction (Year)
240	0.339	6%		
360	0.341	6%	0.049	61.22
720	0.346	6%		

TABLE 6.
LIFESPAN PREDICTION OF GALVANIZED & STAINLESS STEEL WITH SALINITY 3% & FLOW VELOCITY 6.83M/S

Material	Corrosion Rate	Salinity	Average Corrosion Rate	Lifespan Prediction (Year)
	0.719	3%		
Galvanized Steel	0.742	3%	0.718	5.571
	0.693	3%		
	0.046	3%		
Stainless Steel	0.046	3%	0.046	65.21
	0.045	3%		

TABLE 7.
LIFESPAN PREDICTION OF GALVANIZED & STAINLESS STEEL WITH SALINITY 3% & FLOW VELOCITY 3.45M/S

Material	Corrosion Rate	Salinity	Average Corrosion Rate	Lifespan Prediction (Year)
	0.543	3%		
Galvanized Steel	0.580	3%	0.564	7.092
	0.570	3%		
	0.046	3%		
Stainless Steel	0.046	3%	0.046	65.217
	0.045	3%		

E. Micro Structure of Stainless-Steel Pipe

Figure 3 results obtained from micrographs used to observe the morphological characteristics of the surface after conducting corrosion rate experiments. In a single test, three spots were captured within a test specimen at magnifications of 50x, 100x, and 1000x. This was done to gain an overall view of the surface morphology of the SS 304 specimen. Figure 3 (a) represents the micrograph of the SS 304 pipe before immersion. The micrograph reveals the phases of SS 304 pipe, which include pearlite and ferrite. Pearlite is indicated by brighter color composition, while ferrite is depicted by darker composition.

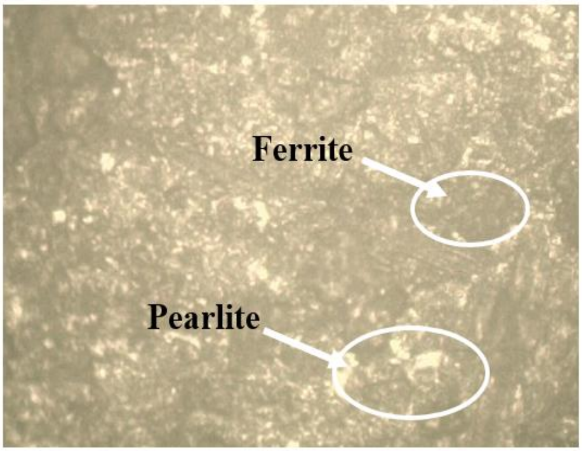
The distribution of pearlite and ferrite grains appears relatively uniform. In Figure 3 (b), the micrograph of the SS 304 pipe after immersion in the NaCl solution shows varying degrees of corrosion-induced damage. The SS 304 pipe exhibits pitting and surface flaking, particularly on the lateral sides. This is influenced by the composition of the SS 304 pipe material, specifically, chromium (Cr) and nickel (Ni), which play crucial roles in the corrosion resistance of SS 304 pipes. Higher levels of Cr and Ni content result in increased corrosion resistance.

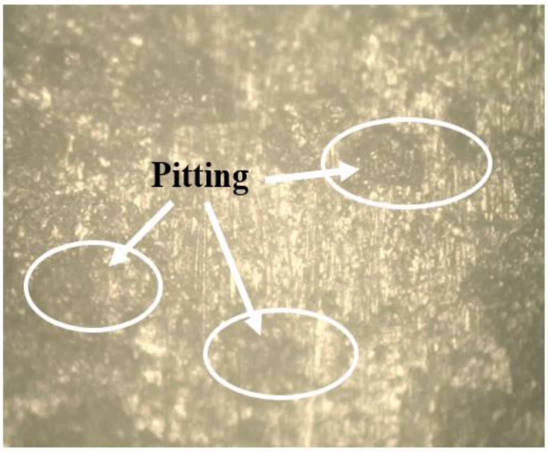
F. Micro Structure of Galvanized Steel Pipe

Figure 4 below shows the micrograph results of a galvanized steel pipe specimen, revealing the surface before immersion in a non-corrosive NaCl solution. Initially, at a magnification of 1000x, the surface appears smooth. The micrograph displays the phases present in the galvanized steel pipe, consisting of pearlite and ferrite, which are evenly distributed throughout the specimen. On the other hand, Figure 4 (b) demonstrates the micrograph results of the galvanized steel pipe after immersion in the NaCl solution.

Clear evidence shows that the galvanized steel pipe exhibits corrosion pits throughout the surface, especially on the lateral sides of the specimen. However, these pits are not found in the areas with black spots. In the corrosion pits, the NaCl solution corrodes the protective layer of the galvanized steel surface, primarily composed of zinc (Zn), which leads to the exposure of pores in the galvanized steel. As a result, the corrosive solution penetrates and damages the metal structure.

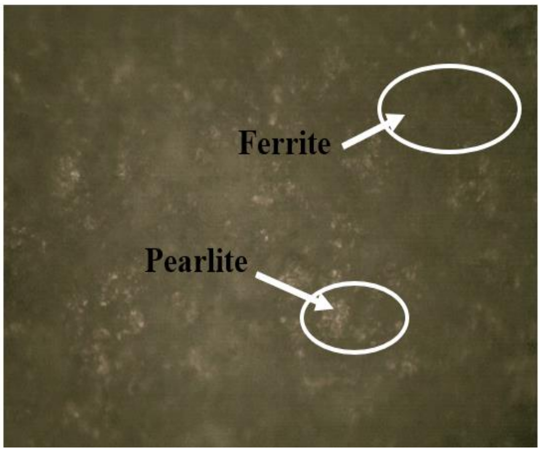
It shows evidence that the corrosion product of galvanized steel pipes contains elements such as zinc, iron, oxygen, carbon, and sodium. This finding reinforces the dominance of compounds like Zincite (ZnO) in the formed corrosion products. The analysis

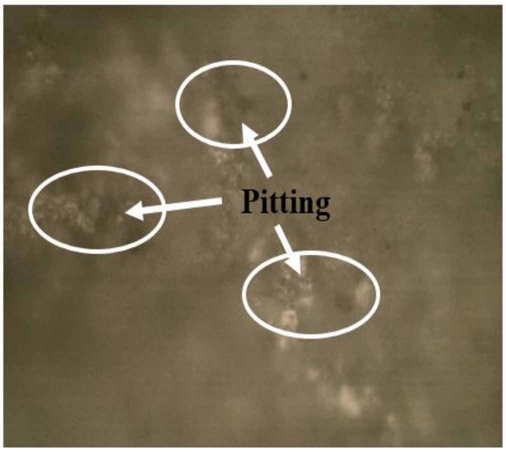




(a) (b)

Figure. 3. (a) Micrograph results of SS 304 pipe before immersion and (b) after immersion.





(a) (b)

Figure. 3. (a) Micrograph results of Galvanized pipe before immersion and (b) after immersion.

above clearly indicates that the corrosion occurring on galvanized steel pipes is more uniform compared to that on SS 304 pipes, resulting in a higher corrosion rate for galvanized steel pipes than SS 304 pipes. One of the main factors contributing to this difference in corrosion rate is the composition of the pipe materials.

IV. CONCLUSION

From the experiment, it can be concluded that the corrosion rate value was influenced by the immersion time and salinity and the flow velocity. It is evident that an increase in salinity leads to an escalation in the corrosion rate, similarly, higher flow velocities result in an increased corrosion rate. Therefore, the lifespan of the tested materials is also influenced by these factors. It has been observed that stainless steel pipes have a higher lifespan compared to galvanized pipes. This is also influenced by the characteristics of the composition of stainless steel and galvanized steel materials itself.

REFERENCES

[1] Sankara Papavinasam, “Corrosion Control in the Oil and Gas Industry”. 1st Edition, 2013. Hardback ISBN: 9780123970220.

[2] Alireza Bahadori, “Corrosion and Materials Selection A Guide for the Chemical and Petroleum Industries”. 1st Edition, 2014. Wiley ISBN: 9781118869208.

[3] Branko N. Popov. “Corrosion Engineering: Principles and Solved Problems”. 2015. Elsevier. https://doi.org/10.1016/C2012-0-03070-0

[4] Mohinder L. Nayyar, P.E, “Piping Handbook”. 7th Edition. 2000. ISBN 0-07-047106-1

[5] Gerhardus H. Koch, Michiel Peter Hein Brongers. G. Thompson, “Corrosion Cost and Preventive Strategies in the United States”. 2001.

[6] Charles Becht. “Process Piping: The Complete Guide to the ASME B31.3, Fourth Edition”. 2021. ASME. 9780791883792

[7] Karan Sotoodeh, “Analysis and Improvement of Material Selection for Process Piping System in Offshore Industry”. *American Journal of Mechanical Engineering*, 2018, Vol. 6, No. 1, 17-26, DOI:10.12691/ajme-6-1-3.

[8] Fei Du et al., “Life Cycle Analysis for Water and Wastewater Pipe Materials”. 2012. Journal of Environmental Engineering. Volume 139, No 5. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000638

[9] Tanzer Satir, “Ballast water treatment systems: design, regulations, and selection under the choice varying priorities”. 2014. Environmental Science and Pollution Research. DOI: 10.1007/s11356-014-3087-1

[10] Junko Kazumi, “Ballast Water Treatment Technologies and Their Application for Vessels Entering the Great Lakes via the St. Lawrence Seaway”. 2007. Transportation Research Board Special Report 291- Great Lakes Shipping, Trade, And Aquatic Invasive Species.

[11] Md. Imteaz Ahmed et al., “Determination of Corrosion Rate of Mild Steel in Different Medium Measuring Current Density”. 2017. Conference: 4th International Conference on Mechanical Engineering and Renewable Energy ICMERE 2017.

[12] Hall, Jane, and Glenn Hollins. "Corrosion Rate Measurement using Electrochemical Technique." Paper presented at the CORROSION 2016, Vancouver, British Columbia, Canada, March 2016.

[13] William Hawkes, “The Principle Mechanisms of Corrosion”. 2020. Graduate Diploma Spring Term 2013-2014.

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

[15] ASTM-G01–03. (2011). Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens. Annual Book of ASTM Standards, 1–9. https://doi.org/10.1520/G0001-0.