



Evaluation of a Green Chemical as Corrosion Inhibitor

Mohammed Hamed Elmahi^a, Ali Abdallahi Eltayeib^b, Yasir Abdalla Dafaalla Ali^c

^a Department of Chemical Engineering, Faculty of Engineering, Kordofan University, Sudan.

^b Department of Chemistry, Faculty of Science, Kordofan University, Sudan.

^c Department of Refining and Petrochemical Engineering, Faculty of Petroleum and Water Engineering, Alsalam University.

Abstract:

Corrosion is a very serious and common issue in the chemical and petroleum industry. It is considered as major flow assurance challenge during oil and gas processing which lead to severe safety and economic losses. There are several ways to prevent or mitigate corrosion, including adding inhibitors. Inorganic corrosion inhibitors are widely used. However, their usage has been restricted due to environmental concern. Green organic compounds inhibitors are proposed to replace the conventional inhibitors, as they are less toxic. In this work, glycerin was proposed as corrosion inhibitor. Different concentration of glycerin solutions was prepared in the range of 100-10000 ppm. The corrosion test will be conducted using weight loss method to assess the performance of the inhibitor. The Conductivity and pH were measured. The results showed that glycerin can act as corrosion inhibitor for carbon steel metal exposed to both distilled water and seawater. The glycerin is more effective at higher concentrations compared to low concentration. The glycerin can inhibit the corrosion in seawater more effectively compared to distilled water. The pH of glycerin solutions prepared in distilled water and seawater decreases with increasing the concentration. The pH of glycerin solutions prepared in seawater is higher than distilled water. The electrical conductivity of seawater is higher than distilled water due to presence of salts. The electrical conductivity of glycerin solutions prepared in seawater decreases with increasing concentration contrary to the distilled water samples.

Keywords:

Green Chemical, Corrosion Inhibitor, glycerin, distilled water, seawater

Introduction:

Corrosion is the surface wastage that occurs when metals are exposed to reactive environments, and the result of interaction between a metal and environments, which result in its gradual destruction, and is an aspect of the decay of materials by chemical or biological agents [1].

Corrosion is a natural process, just like water, flows to the lowest level; all-natural processes tend toward the lowest possible energy states. Thus, for example, iron and steel have a natural tendency to combine with other chemical elements to return to their lowest energy states. In order to return to lower energy states, iron and steel frequently combine with oxygen and water, both of which are present in most natural environments, to form hydrated iron oxides(rust), similar in chemical composition to the original iron ore. Figure 1 illustrates the corrosion life cycle of a steel product [2].

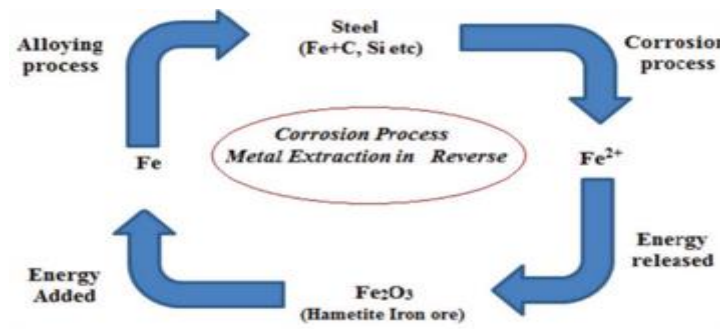


Figure (1): Corrosion Process [3]

Types of corrosion:

1. Galvanic corrosion: Galvanic corrosion will occur when two separate metals/alloys are in contact with each other. These types of corrosion will occur.

- a) When metals are electrochemically dissimilar
- b) Metals are in electrical contact
- c) Metals are exposed to electrolyte, (figure 2).



Figure (2): Galvanic Corrosion

2. Uniform corrosion: Irons and steels will corrode in uniform when exposed to certain environments such as soils and natural waters. Rust will appear in the presence of uniform corrosion, (figure 3).



Figure (3): Uniform Corrosion

3. Pitting corrosion: Spots and pits will appear on the metal with this type of corrosion. It is a type of localized corrosion, which means that the attack is accelerated due to exposure of an area on the metal, that the protective coating or layer has broken down.



Figure (4): Pitting Corrosion

4. Stress corrosion cracking: Unexpected sudden failure can occur with this type of corrosion. Attack of alloys tensile strengths at high temperatures is a common situation for stress-corrosion cracking [5].



Figure (5): Stress Corrosion Cracking

5. Hydrogen Damage: Hydrogen embrittlement is the process that causes most metals to become brittle and more breakable, due to their exposure to hydrogen. Hydrogen embrittlement usually occurs unintentionally during metal forming processes, where the element hydrogen enters between the molecules of the material causing the process of hydrogen embrittlement [6].



Figure (6): Hydrogen Damage

Electrochemical mechanism:

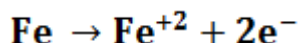
Wet corrosion is based on an electrochemical mechanism in which two-reaction sum up to give the overall corrosion process; a cathodic reaction that consumes electrons and an anodic one, where electrons are released by the metal oxidation. The electrochemical mechanism is examined in details, and the most important anodic and cathodic processes are described. From these basic principles stoichiometric considerations will be drawn, leading to the correlation between corrosion rate and current density by the use of faraday law [7].

The corrosion of a metal, M, can be expressed by the following general reaction:

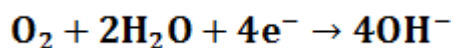


If the environment is an electrolyte (aqueous or wet corrosion) the corrosion reaction is the sum of two electrochemical reactions, an anodic process which consists of the oxidation of the metal, A cathodic process is a reaction, typically oxygen reduction or hydrogen ion reduction.

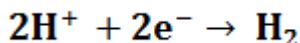
In the case of iron, the anodic reaction is [8];



Where electrons are made available: these electrons are taken by the cathodic reaction, for instance by oxygen, with production of alkalinity [9]:



Or by hydrogen ions in the case of an acidic solution, with consumption of acidity (i.e. production of alkalinity) [7];



In addition to above reaction , a corrosion process implies two further processes, namely [10]: (1) an electron flow within the metal from the anodic area, where electrons are released, to the cathodic zone, where electrons are consumed; the electron flow direction is opposite to the conventional current direction (since electron charge is negative). (2) a current flow (circulation) within the electrolyte by ion transportation, from the anode to the cathode zone ; positive ions move in the same direction of current and negative ions in the opposite one. In short, a corrosion process consists of four processes in series [11].

Methodology:

In this study, the experiment work consisted of two main parts according to the objectives.

The first part is a test of the corrosion rate for carbon steel in seawater and distilled water solutions containing glycerin at different concentration.

The second part test is electrical conductivity.

Materials: Carbon steel samples are used for the corrosion study. Carbon steel commonly used is pipeline grade for oil and gas pipelines. Because the rate of corrosion is also affected by the condition of the mineral samples, the sample is prepared as accurately as possible. However, fine scratches lead to a high rate of corrosion. A piece of carbon steel with known dimension is prepared. The samples are scraped using abrasive papers to obtain a homogeneous and smooth surface. Rinse with distilled water to remove impurities.

The metal samples are immersed in pre prepared glycerin solutions. The concentration of the glycerin solutions is in the range of 100 – 10000 ppm. The purity of glycerin used in this study is 99 %.The prepared samples were divided into two groups. The first group prepared in distilled water and the second group in seawater.

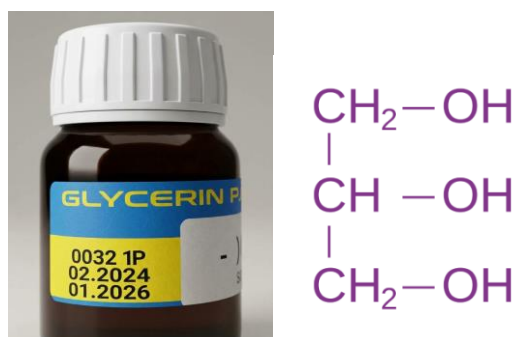


Figure (7): Glycerin Used In This Project

Procedure:

Weight Loss Method: Before immersion in the solutions, the metal samples were first cleaned and weighed. Mineral samples (carbon steel) having known dimensions and specific weight were dropped into 300 ml in inhibited and uninhibited system and left for 37 days at normal temperature and pressure. The difference in mass will be evaluated after the mentioned time. After 37 days, the mineral samples are withdrawn and washed with distilled water.

Sample preparation: Carbon steel mainly consists of carbon and iron compounds and it is commonly used for the piping and valves in refineries and petrochemical plants because of its low cost. However, it is not commonly used for piping and valves in offshore environments owing to its low corrosion resistance.

Carbon steel was obtained from Sirte oil and gas production manufacturing company. Some of these samples were used in transporting crude oil and other were used in transporting gas from fields



Figure (8) Carbon Steel Sample

Carbon steel is divided into three parts (cutting, cleaning, and measuring). Cutting: at this stage, large carbon steel is cut into small pieces with known dimensions and equal sides. The shape of the samples was shown in figure 9.



Figure (9): Samples after Cutting

Cleaning: After cutting the carbon steel samples, we move to an important stage, which is surface finishing, which is done by scraping each of the samples separately using abrasive papers until we obtain smooth surface.



Figure (10): Samples Before and After Cleaning

Measuring: Measurements and weights were taken after completing the surface finishing of the samples. This process took place in two stages: in the first stage, the samples were taken and weighed in the laboratories of the Libyan Fertilizer Company.

In the second stage, the dimensions of the samples were taken and the area of each sample was calculated using the vernier caliper in the laboratories of the Department of Chemical Engineering at Bright Star University.

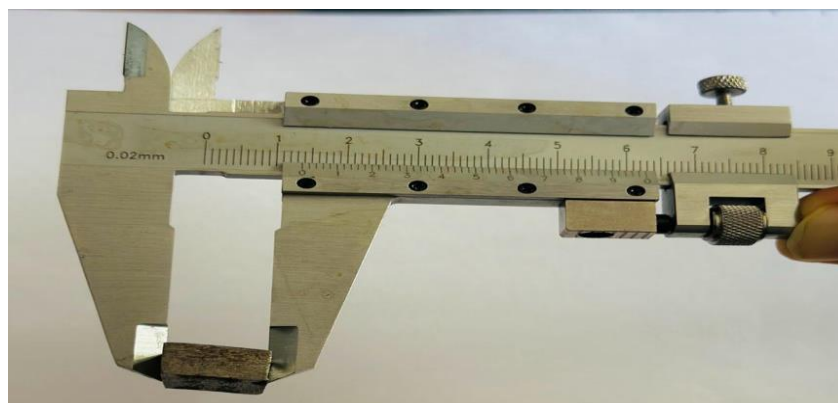


Figure (11): Taking the Dimensions

Pure glycerin was chosen as an environmentally friendly corrosion inhibitor. A study was conducted on its inhibitory effectiveness on samples of carbon steel. Glycerin was in varying concentration within two corrosion environments, which were solution of (seawater and distilled water), where the glycerin concentrations were calibrated as follows: (100 – 500 – 1000 – 5000 – 10000 ppm).

At room temperature, carbon steel samples with known dimensions and known initial weights were immersed and left in the solution for a period of 37 days. After taking all sample data from surface areas and weights, each of the solution (seawater and glycerin) with a weight of 300 ml of seawater and varying concentration of glycerin were placed in five separate bowls filled with seawater only with the submerged sample. The glycerin solutions were weighted and prepared for the five different concentration (100 -500 – 1000 – 5000 – 10000 ppm) using a sensitive balance in the Libyan Fertilizer Company Laboratory. Then add it to seawater. The same steps were repeated with distilled water. We wait for 37 days, and after that the results were taken. The final mass of the samples is evaluated to obtain a constant weight and the weight loss and corrosion rate are calculated by equation:

$$C_{rate} = \frac{\Delta m}{p.A.t}$$

Where Δm is mass loss, ρ is mass metal density, A an area of the specimen, and t is time. The most frequently used units of measurement of thickness loss rates are mm/y and mpy (mils per year) (1mpy = 0.025 mm/year or 25.4 μm /year). After calculating the corrosion rate, we can calculate the efficiency of the inhibitor according to the following equation:

$$\text{Efficiency} = 100 \times \frac{C_{rate} - C_{rate,inh}}{C_{rate}}$$

$$C_{\text{rate}}$$

Where C_{rate} and $C_{\text{rate-inhib}}$ are corrosion rates in the absence and in the presence of an inhibitor, respectively.

pH Measurement:

pH is a measure of the acidic or basic (alkaline) nature of a solution. The concentration of the hydrogen ion $[H^+]$ activity in a solution determines the pH. As pH has major effect on corrosion, in this research, the pH value of the glycerin solutions is evaluated using a pH meter supplied by Thermo scientific company with accuracy of ± 0.01 .

Conductivity measurements:

The conductivity of a liquid is a measure of charged particles, called ions that are free to move around. The conductivity itself is carried by the ions and the more ions there are in a solution, the higher is the conductivity (Nelson, 2017). A liquid solution consisting of compounds that completely break apart into ions have a high conductivity. As conductivity has major effect on corrosion, in this research, the conductivity value is studied using a conductivity meter supplied by Thermo scientific company with accuracy of $\pm 0.01 \mu S$.

Results and Discussions:

Evaluation of performance of glycerin as corrosion inhibitor:

After the 37 days period, the metal samples are cleaned, weighed and the steps are repeated until the variation between readings are negligible and the mass became constant. The results are presented in tables and figures.

Samples prepared in distilled water:

To eliminate the effect of ions on the corrosion rate, the metallic samples were immersed in glycerin solutions prepared at different concentration using distilled water. The samples were kept at room temperature $25^\circ C$.

The results are presented in the table and shown in figure.

Table (1): Corrosion rate of samples contain different concentrations of glycerin in distilled water.

Concentration (ppm)	Initial weight (g)	Final Weight (g)	Surface area (cm ²)	weight loss (g)	MPY	$\mu m/\text{year}$
0	6.8760	6.8537	0.4482	0.0223	3.812	96.818
100	7.4387	7.414	0.6711	0.0247	2.820	71.618
500	10.4567	10.4298	0.7053	0.0269	2.922	74.212
1000	9.3403	9.319	0.5739	0.0286	2.843	72.218
5000	10.1656	10.1352	0.8468	0.0304	2.750	69.856
10000	9.8565	9.8289	0.8524	0.0276	2.480	63.003

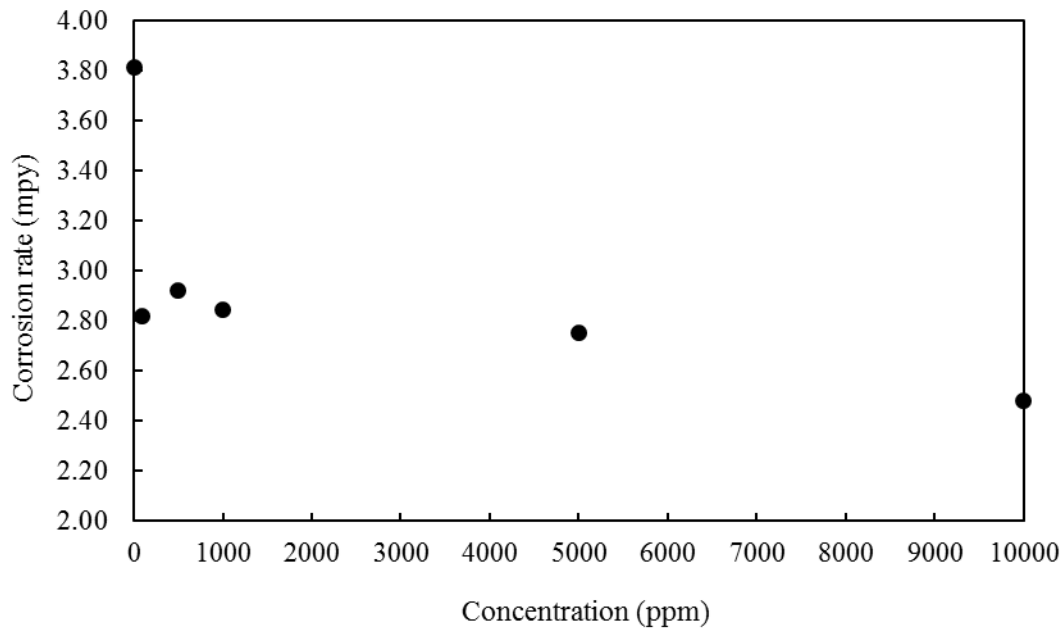


Figure (12): The corrosion rate of samples tested in glycerin solutions prepared in distilled water.

It can be observed from the figure (12) and table (1) that in the absence of glycerol the corrosion rate of carbon steel in distilled water is approximately 3.812 mpy. Addition of glycerol significantly reduces the corrosion rate. According to the Table (1), the corrosion rate classified as a very good either in the present or absence of corrosion inhibitor.

In order to analyze the performance of glycerin as corrosion inhibitor, the inhibition efficiency was calculated and plotted in figure (13) and listed in table (2).

Table (2): The inhibition efficiency of glycerin prepared in distilled water.

Concentration (ppm)	Efficiency %
100	26.03
500	23.35
1000	25.41
5000	27.85
10000	34.93

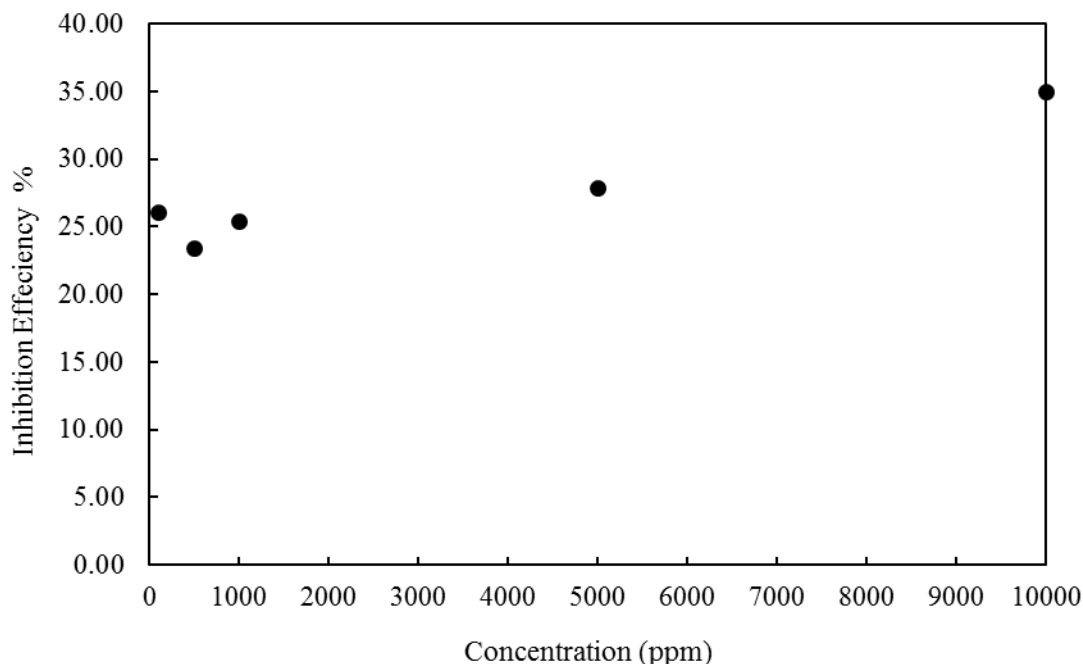


Figure (13): The inhibition efficiency changes with concentration of glycerin prepared in distilled water.

It can be shown that the inhibition efficiency increases with increasing concentration of glycerin. The presence of three polar groups such as $-OH$ contributes to the formation of bonds with the surface, involving interactions of chemical nature. This type of adsorption is denominated at chemisorption. Electron transfer between the metal and the inhibitor forms this bond through a coordinate link. These groups are the sites used by the organic molecules to adsorb onto the metal. The strength of the coordinate bond between the metal and the reactive groups depends upon the electron density on the donor atom of the functional group and the polarizability of the group. Therefore, increasing the polarizability by adding electron-donor groups to the inhibitor molecule provokes an increase in the strength of the coordinating bond, which raises the corrosion inhibitor efficiency.

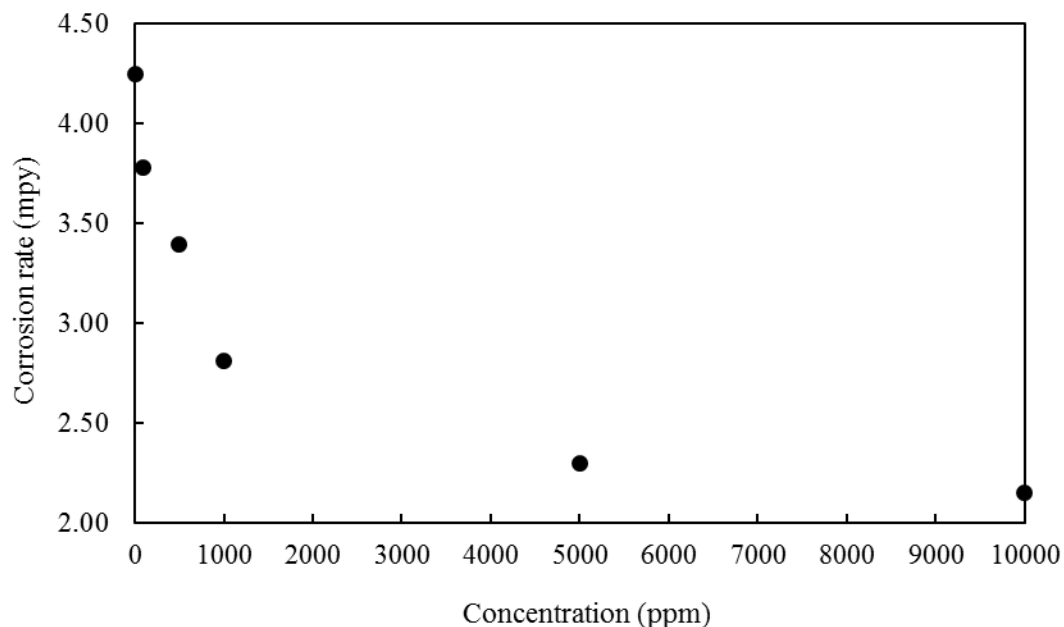
Samples prepared in seawater:

The corrosion rates of carbon steel samples were tested in glycerin solutions prepared in seawater. As well known, salt water is encountered in many industrial applications such as oil and gas production and transportation. Therefore, it is crucial to study the performance of glycerin in seawater.

The results obtained after 37 days is tabulated in table (3) and plotted in figure (14). It can be observed that the glycerin reduces the corrosion rates at all concentrations. Moreover, increasing the concentration of glycerin decreases the corrosion rate.

Table (3): Corrosion rate of samples contain different concentrations of glycerin in seawater

Concentration (ppm)	Initial weight (g)	Final Weight (g)	Surface area (cm ²)	weight loss (g)	mpy	µm/year
0	8.6458	8.6150	0.5558	0.0308	4.2454	107.832
100	8.3912	8.3664	0.5025	0.0248	3.7805	96.025
500	7.6382	7.6110	0.6142	0.0272	3.3927	86.175
1000	9.5928	9.5600	0.8931	0.0328	2.8134	71.460
5000	8.2808	8.2590	0.7261	0.0218	2.2999	58.418
10000	8.0095	7.9950	0.5162	0.0145	2.1520	54.660

**Figure (14): The corrosion rate of samples tested in glycerin solutions prepared in seawater**

It also observed from figure (15) and table (4) that the increase of inhibition efficiency with the increased concentration of glycerin prepared in sea water can be explained with the same explanation used for distilled water.

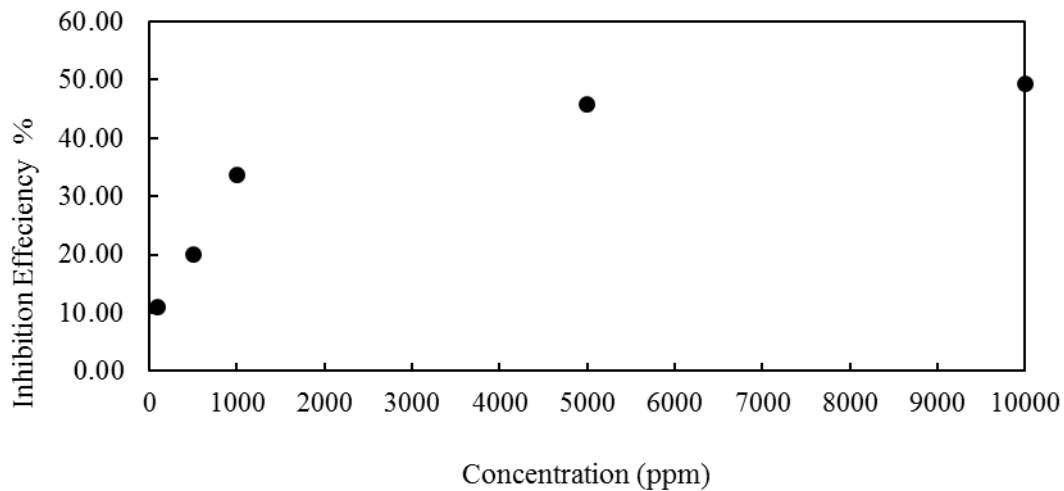


Figure (15): The inhibition efficiency changes with concentration of glycerin prepared in seawater.

Table (4): The inhibition efficiency of glycerin prepared in seawater.

Concentration (ppm)	Efficiency %
100	10.95
500	20.08
1000	33.73
5000	45.83
10000	49.31

Understanding the mechanisms behind seawater corrosion is crucial for various industries and applications, from maritime shipping and offshore infrastructure to desalination plants and coastal construction. By employing corrosion-resistant materials, protective coatings, and cathodic protection techniques, we can mitigate the damaging effects of seawater and ensure the longevity of structures and equipment exposed to this harsh environment.

Comparison between seawater samples and distilled water samples:

By comparing the corrosion rate in seawater and distilled water samples, it can be concluded that seawater causes higher inhibition rate due to several factors.

- Electrolyte nature of seawater makes it a good conductor of electricity due to the dissolved salts like sodium chloride (NaCl). This electrolyte characteristic facilitates the flow of ions that drive the electrochemical corrosion process. In simpler terms, seawater acts as a battery, accelerating the oxidation of metals.

- Chloride ions: These tiny villains play a critical role in breaking down protective oxide layers that naturally form on some metals. By breaking this barrier, they expose fresh metal to further corrosion.
- Dissolved oxygen: Oxygen present in seawater acts as the "electron acceptor" in the corrosion reaction, further fueling the process. Higher oxygen levels often lead to faster corrosion.

Acidity: While seawater has a slightly alkaline pH, localized areas around corroding metals can become acidic due to the release of hydrogen ions. This acidic environment further degrades the metal.

Although corrosion rates are higher in seawater samples, the inhibition efficiency of glycerin in seawater samples are higher at concentration above 500 ppm while the glycerin is more effective in distilled water at low concentration as shown in figure (16).

This could be due to the fact seawater has a much higher ionic strength and conductivity than distilled water due to the presence of dissolved salts. This affects the adsorption and interaction of inhibitor molecules with the metal surface. Some inhibitors are better suited for high ionic environments like seawater, allowing them to form strong protective films on the metal. In addition, seawater contains various other ions beyond chloride, like magnesium and sulfate. Some inhibitors can interact synergistically with these ions, enhancing their protective capabilities by forming more stable and adherent films on the metal.

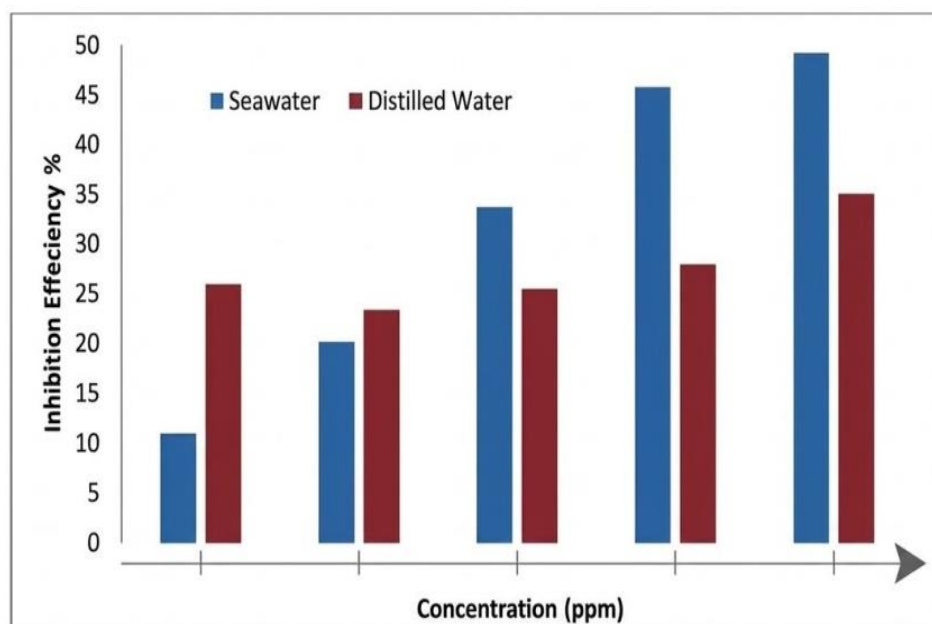


Figure (16): Comparison of inhibition efficiency between Seawater samples and distilled water samples

pH measurement of glycerin solutions:

As it has mentioned earlier, the performance of corrosion inhibitors are highly affected by pH. Therefore, the pH was measured in this study for all samples at room temperature 25°C. The

efficiency of the inhibitor decreased with increasing acidity. Hence, if an inhibitor is employed its performance must be known according to the pH of the solution. The pH study was conducted on the inhibitors to know the pH stabilization effect in the solution to prevent corrosion.

In particular, pH plays an important role because it influences the anodic and cathodic reaction. If pH enables passivation, the inhibitor helps strengthen the oxide existing film. Conversely, when an oxide film cannot form, the inhibitor builds a protective film by adsorption at the surface.

Table (5): pH of glycerin solutions prepared in seawater and distilled water.

Concentration (ppm)	Seawater	Distilled water
0	8.36	6.90
100	8.34	6.76
500	8.16	6.75
1000	8.09	6.69
5000	7.82	6.65
10000	7.12	6.62

It can be seen from table 5 that the pH of seawater is higher than distilled water due to presence of different dissolved ions in sea water. The addition of glycerin reduces the pH value. This result is agreed with data presented in [Vinayagam Sivabalan].

Conductivity measurement of glycerine solutions:

The electrical conductivity has significant impact on the corrosion rate as the presence of more ions could lead to higher corrosion rate. Therefore, the electrical conductivity was measured at room temperature 25°C. Table (6) presents the electrical conductivity of glycerine solutions either in seawater or distilled water.

Table (6): Conductivity of glycerin solutions prepared in seawater and distilled water.

Concentration (ppm)	Seawater	Distilled water
JETIR2610193	Journal of Emerging Technologies and Innovative Research (JETIR) www.jetir.org	b889

0	55700	2.00
100	57500	2.11
500	57400	2.15
1000	57200	2.20
5000	57000	2.28
10000	56300	2.75

It can be observed that the electrical conductivity of seawater samples is higher than the distilled water samples due to the ions present in seawater. The electrical conductivity increases with glycerine concentration for distilled water samples. This due to the presence of more ions in the sample. However, seawater showed an opposite trend as increasing the glycerine concentration decreases the conductivity. This happens because glycerine molecules, being less conductive than the dissolved salts in seawater, hinder the movement of ions within the solution. They act as "spacers" between the ions, reducing the overall charge flow and therefore, the conductivity. Moreover, the impact on conductivity is dependent on the concentration of glycerine added. Higher concentrations lead to more "insulating" glycerine molecules in the solution, further lowering the conductivity.

Conclusion:

Several points can be concluded from this project.

- 1 Glycerin can act as corrosion inhibitor for carbon steel metal exposed to both distilled water and seawater.
- 2 The glycerin is more effective at higher concentrations compared to lower one.
- 3 The glycerin can inhibit the corrosion in seawater more effectively compared to distilled water.
- 4 The inhibition power of glycerin is justified based on the presence of function group -OH which can be adsorbed on the metal surface.
- 5 The pH of glycerin solutions prepared in distilled water and seawater decreases with increasing the concentration.
- 6 The pH of glycerin solutions prepared in seawater is higher than distilled water.
- 7 The electrical conductivity of seawater is higher than distilled water due to presence of salts.
- 8 The electrical conductivity of glycerin solutions prepared in seawater decreases with increasing concentration contrary to the distilled water samples.

Reference:

1. Ahmad, Z. (2006). *Principles of corrosion engineering and corrosion control*. Elsevier.

2. Davis, J. R. (Ed.). (2000). *Corrosion: Understanding the basics*. Asm International
3. Palanisamy, G. (2019). Corrosion inhibitors. *Corrosion inhibitors*, 1-24.
4. Pedferri, P., & Ormellese, M. (2018). *Corrosion science and engineering* (p. 720). Cham, Switzerland: Springer.
5. Salleh, S. Z., Yusoff, A. H., Zakaria, S. K., Taib, M. A. A., Seman, A. A., Masri, M. N., ... & Ter Teo, P. (2021). Plant extracts as green corrosion inhibitor for ferrous metal alloys: A review. *Journal of Cleaner Production*, 304, 127030.
6. Kadhim, A., Al-Amiery, A. A., Alazawi, R., Al-Ghezi, M. K. S., & Abass, R. H. (2021). Corrosion inhibitors. A review. *International Journal of Corrosion and Scale Inhibition*, 10(1), 54-67.
7. Montgomery, M. A. & Elimelech, M. Water and sanitation in developing countries: including health in the equation. *Environ. Sci. Technol.* 41, 17–24 (2007)
8. Shang, Z., & Zhu, J. (2021). Overview on plant extracts as green corrosion inhibitors in the oil and gas fields. *Journal of Materials Research and Technology*, 15, 5078-5094.
9. Buchweishaija, J. (2009). Phytochemicals as green corrosion inhibitors in various corrosive media: a review. *Tanzania Journal of Science*, 35.
10. Fazal, B. R., Becker, T., Kinsella, B., & Lepkova, K. (2022). A review of plant extracts as green corrosion inhibitors for CO₂ corrosion of carbon steel. *npj Materials Degradation*, 6(1), 5.
11. Finšgar, M., & Jackson, J. (2014). Application of corrosion inhibitors for steels in acidic media for the oil and gas industry: A review. *Corrosion science*, 86, 17-41.
12. V. Sivabalan, B Walid, Y Madec, A Qasim, B Lal (2020), Corrosion inhibition study on Glycerol as simultaneous gas hydrate and corrosion inhibitor in gas pipelines, *Malaysian Journal of Analytical Sciences* 24 (1), 62-69.