

EXPERIMENTAL STUDY ON ASCORBIC ACID ADDITIVE AS GREEN INHIBITOR AGAINST CORROSION OF MILD STEEL

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Abstract

Purpose of study: The corrosion behavior of mild steel and the inhibition effect of ascorbic acid (an anti-oxidant additive) on aluminum coatings on the mild steel have been studied by weight loss technique under different corrosive medium.

Methodology: Tap water, 3% Na₂CO₃ solution, seawater and open-air were chosen as different corrosive medium at ambient temperature range of 35- 40°C. Corrosion was recorded using the weight loss method, and the rate was calculated. Later similar mild steel samples were coated with Sodium Bicarbonate paste, aluminum paint with ascorbic acid additive, and aluminum paint without ascorbic acid additive, in the same corroding medium, and the corrosion rate was calculated using weight loss method.

Main Findings: Results show that the percentage of mild steel corrosion was found to be highest in the seawater and lowest in 3% Na₂CO₃ solution. Sodium Bicarbonate paste reduces the corrosion rate more studies on the corrosion protection was performed by coating the mild steel surface with aluminum paint along with ascorbic acid inhibitor, i.e., a green corrosion inhibitor, and it was found that the weight loss data is: 85.03 g from 85.05 g, 82.39 g from 82.43 g, no weight loss and 85.73 g from 85.74 g in tap water, seawater, 3% Na₂CO₃ solution and air medium respectively. Thus, the addition of ascorbic acid inhibitor gave the highest inhibition efficiency for aluminum paint.

Keywords: mild steel, corrosion, anti-oxidant additive, ascorbic acid, weight loss method

INTRODUCTION

The deterioration of a substance or its properties because of the interactions between the substance and its environment is known as corrosion ([Adejoro et al., 2015](#)). It is a global phenomenon, making enormous economic and environmental impacts on all facets of infrastructure such as highways, bridges, buildings, oil and gas, chemical processing, water and wastewater treatment, and also on all metallic objects in use. With the material loss, it also interferes with human safety, disrupts industrial operations; thus, it is a danger to the environment. The main factors responsible for metal corrosion include- the grain structure of the metal, its composition during alloying, temperature, the reactivity of metal, presence of impurities, presence of air, moisture, gases like Sulphur dioxide, carbon dioxide, and presence of electrolytes. Corrosion can be reduced by the methods which retard or stop the anodic or cathodic reactions, so for this, such type of corrosion inhibitors ([Gupta et al., 2017](#), [Alibakhshi et al., 2018](#)) can be used which are mostly organic compounds; therefore, there is a great need of eco-friendly corrosion inhibitors ([Varma et al., 2014](#)) to replace inorganic and organic inhibitors. One of the natural chemical compounds that can be used as the corrosion inhibitor ([Fuchs-Godec et al., 2013](#)) is ascorbic acid ([Rani et al., 2012](#)), which is cheap and nontoxic.

On the basis of the previous research done by Pradityana et al. in 2015, it becomes clear that *Myrmecodia Pendans* can be used as an organic inhibitor for carbon steel, and thus, this study investigates the mechanism of *Myrmecodia Pendans* as a corrosion inhibitor ([Pradityana et al. 2016](#)). In the year 2017, de Oliveira et al. investigated the corrosion Behavior of high-strength, low-alloy (API 5L X80) steel in produced water systems with and without microorganisms for 60 days and the microbiological composition of produced water has been quantitatively characterized ([de Oliveira et al., 2017](#)) and they found that the corrosion products formed in the biotic system were Fe(OH)₃, Fe(OH)₂, FeOOH, Fe₃O₄, FeS₂, FeCl₃, and in the abiotic system, NaCl, CaCl₂ and SrSO₄. BaSO₄ and CaCO₃, identified in both systems. In a similar manner, Bodude et al. have also reported in 2013 the corrosion behavior for API 5LX60 steel ([AlAbbas et al., 2013](#)). Because of the incessant explosion of oil and gas pipelines and corrosion of the pipeline material, various environmental problems are there. API 5LX60 steel samples were completely immersed in different concentrations of chloride, sulfide, and carbonate ions media, and their electrode potentials and weight loss were measured. The results indicate that the highest and lowest corrosion rate are in the chloride ion and sulfide ion media, respectively.

In the year 2012, Ajide et al. compared the corrosion resistance of carbon steel (MCS) and KS7 stainless steel by exposing them to 0.5M of H₂SO₄, HCl and HNO₃ environment for 36 days, and weight loss was taken after every three days to evaluate CPR. This study shows that KS7 SS offered good corrosion resistance as compared to the MCS in the acid's media taken. So there study results ([Ajide et al. 2012](#)) clearly depict that MCS is an unsuitable alloy in Sulphur, nitric, and hydrochloric acid environments, and KS7 SS is a good choice material for the purpose of fabrication of engineering machines and tools.

Karthik et al. in 2016 studied the inhibition performance of atenolol on mild steel in 1 M hydrochloric acid solution. Atenolol is very cheap, readily available, environmentally friendly, nontoxic as well. They investigated the corrosion process of mild steel in 1 M hydrochloric acid solution in the absence as well as the presence of different concentrations of atenolol, by weight loss measurements in 100 ml 1 M HCl solution at room temperature for 3 hours immersion period. This study revealed (Karthik et al. 2016) that atenolol effectively inhibits the corrosion of mild steel in 1 M HCl solutions, as the inhibitor molecule gets adsorbed on the mild steel surface. This results in a reduction of corrosion, increase in the inhibition efficiency of the compounds with the increase in the atenolol concentrations. This adsorption of atenolol on mild steel surface from 1 M HCl obeys Langmuir adsorption mechanism.

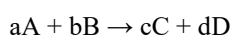
In 2016, Ejieh et al. published a research article in which they discussed about the inhibition of mild steel corrosion in sulphuric acid solution of varying pH values by Piper guineense extract at room temperature by weight loss technique. They found (Ejieh et al. 2016) that the weight loss and corrosion rate decreases with the increase in pH Value, the adsorption of the extract follows physical adsorption mechanism and the weight loss obeyed the first order rate model when the rate constants (k) range from 0.1015-0.1238 and 0.1003-0.1302 and goodness of fit (R^2) varies from 0.9690-0.9835 and 0.9586-0.9912 for the respective cases of uninhibited and inhibited coupons respectively. Mirza et al., in 2016, published a research paper that discusses the behavior of nano-additives used in painted coatings for corrosion protection of steel pipelines in the petroleum industry of Oman. The results show that the highest and lowest corrosion rate was for Z-z and A-a that is 8.46 mmpy and 1.7118 mmpy, respectively. Therefore, they concluded (Mirza et al. 2016) that the order for the strength of corrosion resistance follows the order-aluminum paint, organic paint, and then zinc paint, and the highest corrosion rate was obtained for the sample coated with Z-O that is equal to 5.62 mmpy.

Yue et al. 2015 investigated the corrosion resistance of selected aluminum alloys with various combinations of commercial coatings by applying the Tafel electrochemical method in water and simulated saltwater environments. From their experiments, Yue et al., concluded (Yue et al. 2015) that the corrosion rate values obtained in saltwater were two orders of magnitude higher than those obtained in distilled water. With this, it was also found that the coating combination, i.e., the ceramic coating, primer, etc. exhibited excellent corrosion resistance in comparison to the coating combination of chromate, epoxy coating, primer and topcoat.

Sanni et al., in 2019, have briefly discussed (Sanni et al., 2019) in their review about some of the eco-friendly substances used as corrosion inhibitors for stainless steel. Yang et al., in 2018, published research work in Royal Society of Chemistry in which anticorrosive behavior (Yang et al., 2018) of a zinc-rich epoxy coating containing sulfonated polyaniline in 3.5% NaCl solution has been discussed. The results suggest that a zinc-rich coating, in addition to 1.0 wt% of SPANi, enhances the cathodic protection time and barrier performance.

CORROSION MECHANISM AND PROTECTION TECHNIQUES

For a better understanding of the corrosion mechanism, it is important to understand that the corrosion occurs at the interface of the metal and non-metal. In this process, the metal gets oxidized, and the non-metal gets reduced. The basic principle of the corrosion relies on the fact that the rate of oxidation is equal to the rate of reduction, and thus the chemical reaction in this phenomenon can be written as:



Where A and B are the metal and non-metal respectively, C is oxidized form of the metal corroded (output corrosion), and D is the reduced non-metal.

Many techniques (Umoren et al., 2017; Gupta et al., 2016) are used for corrosion protection (Zuo-anXiao et al., 2017), but here some primary steps must be followed: Material selection- Coatings- Inhibitors- Cathodic protection and Design.

The corrosion protection methods are classified as follows:

- Active corrosion protection
- Passive corrosion protection
- Permanent corrosion protection
- Temporary corrosion protection.

This research work is focused on the most common form of steel that is the mild steel (Zhang et al., 2012), also known as plain-carbon steel. It is cheap (Singh et al., 2016) and also has low corrosion resistance, especially in acidic environments (Alaneme et al., 2016). This steel type is one of the major construction materials, extensively used in chemical and allied industries for handling of acid, alkali and salt solutions. For corrosion protection of mild steel (Khodair et al., 2019; Lu et al., 1995), there are two key steps, namely, surface preparation and its coating. But it is very important to note that the choice of the coating mainly depends on the type of environment in which the mild steel is to be exposed to.

EXPERIMENTAL SETUP AND METHODOLOGY

Materials and Apparatus: Phosphoric acid, Acetone, Potassium Tartrate, Methanol, Hydrogen peroxide, Sodium Bicarbonate, Ascorbic acid, Na_2CO_3 were taken from the laboratory. Aluminum paint and sandpaper were purchased from the local market. Seawater was collected from the North Sea beach. It was filtered and used as such without any

modification at an ambient temperature range of 35- 40°C. Tap water was collected in the laboratory, and a 3% Na_2CO_3 solution was prepared in distilled water.

Sample Cleaning: Mild steel samples were rubbed with sandpaper (grades 500, 1000, 1500, and 2000) to make smooth and then washed with ethanol, acetone, distilled water, and sun-dried. Weight of all the samples were recorded in the lab weighing machine, and then they were dipped in the corrosive medium.



Figure 1: mild steel samples dipped in different in corrosive medium

Weight of samples at a particular time interval: After placing the mild steel samples in the selected medium (figure 1), it becomes indispensable to know as if how the sample weight changes after some time. The mild steel weight was observed and recorded after every two weeks, and sometimes after every three weeks for fourteen weeks, this aids in getting the best results.

Preparation of Sodium Bicarbonate paste and mild steel coating: Sodium Bicarbonate paste was prepared for coating one sample of mild steel, in order to understand the effect of the material, so that corrosion of mild steel gets reduced. Procedure for the preparation of Sodium Bicarbonate paste and mild steel coating (figure 2) is as follows:

- **Preparation of the Sodium Bicarbonate paste:** Sodium Bicarbonate, Potassium bitartrate, and hydrogen peroxide were collected, 28.0 g of Sodium Bicarbonate and Potassium bitartrate were weighed on the weighing machine and then mixed in a clean vessel to make a paste (a little bit thicker than toothpaste).
- **Mild steel coating:** The mild steel sample was cleaned first, covered with the Sodium Bicarbonate paste, and hanged outside. Then the change in weight of the sample was observed and noted down after two weeks or more.

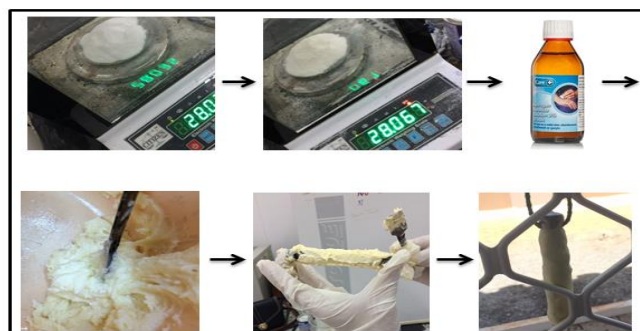


Figure 2: Sodium Bicarbonate paste preparation & mild steel coating

Mild steel coating with aluminum paint: Corrosion can be prevented by coating a metal surface with paint as this coating provides a barrier between the metal and the moisture present in the environment. Here aluminum paint was chosen to determine the effect of the coating. Then mild steel samples were painted with aluminum paint, and the corrosion inhibitor was added to study the effect of paint in reducing the mild steel corrosion. The procedures can be summarized as follows:

- **Procedure of liquid medium:** 0.9 g Na_2CO_3 (powder form) was weighed, then it is dissolved in 300 ml of water, a solution was prepared, placed in a plastic coating bottle. 300 ml of tap water and 300 ml of seawater was placed in a plastic bottle.
- **Mild steel coated with aluminum paint without inhibitor:** four samples of mild steel were cleaned, covered with aluminum paint, left for drying (for 24 hours), and weight of the four samples was noted (figure 3). After this, the samples were dipped into the plastic bottles containing the corrosive medium (figure 4). The samples were hanged outside, and after two or more weeks, the change in weight of samples was noted down.



Figure 3: Mild steel coating with aluminum paint without inhibitor



Figure 4: Samples dipped in different corrosive liquid medium

- **Mild steel coating with aluminum paint and inhibitor:** All the four samples of mild steel were cleaned, 38.25g of ascorbic acid (inhibitor) was added to aluminum paint (figure 5), mixed well, then the samples were coated with aluminum paint, and left for 24 hours for drying up. After this, the weight of the samples was noted. Then the samples were dipped in the plastic bottles containing the corrosive liquid medium (figure 6) and hanged outside; the change in sample weight was observed and noted after two weeks or more.



Figure 5: Mild steel coating with aluminum paint and inhibitor



Figure 6: Samples dipped in the corrosive liquid medium

Weight loss of the mild steel samples in different corrosive medium: This study depends on the weight loss technique to study the corrosion of mild steel in different corrosive media - tap water, seawater, Na_2CO_3 solution, and also air. The change in mild steel weight was observed for four months from February till May 2018. From the extensive analysis of the results obtained in this experiment, it was observed that the weight is inversely related to the corrosion rate of mild steel. This is in fact because of the reason that due to the decrease in the weight of mild steel sample, there is an increase in the rate of corrosion and this has been shown in the following table:

Table 1: weight of mild steel samples in different corrosive medium

Corrosive medium	Tap water	Seawater	3% Na_2CO_3 solution	Air
Starting weight of steel samples	73.66 g	80.86 g	78.75 g	82.23 g

From table 1 and Fig 7, it is clear that the mild steel weight decreases with an increase in time, and the highest rate of weight loss was found in tap water and seawater whereas the lowest rate of mild steel weight loss was found in 3% Na_2CO_3 solution and air medium. During the first week of observation, the original weight of the mild steel sample in tap water was equal to 73.66 g, and after this, the weight started decreasing until it arrived at 73.27g in the fourteenth week. On the other hand, the original weight of the mild steel sample in seawater was found to be equal to 80.86 g in the first week, and after this, it was observed that the weight began to decrease until it arrived at 80.39 g in 14th week. Whereas the original weight of the mild steel submerged in the 3% Na_2CO_3 solution was equal to 78.75 g and decreased until it arrived at 78.68 g. During the first week, the original weight of the mild steel sample that was hanged in the air was equal to 82.23g, which decreased until it arrived at 82.11 g in the fourteenth week. The rate of weight loss in the solution is low because of the slow corrosion of the mild steel. This is due to the low temperature of the solution, a low degree of aggression of the medium, and it is only a lower proportion of the presence of oxide ions in the solution. But it has been noticed that due to the greater presence of oxygen, the metals get more corroded, and this leads to the lowering in the proportion of oxygen in the solution. Similarly, in the case of air, there is lesser weight loss due to less humidity. It was also found that the rate of mild steel weight loss was higher in seawater, and this is actually because of the wet environment and the concentration of the salts. Similar is the case of tap water, as moisture and oxygen both are present, and are the essentials for the medium to corrode more.

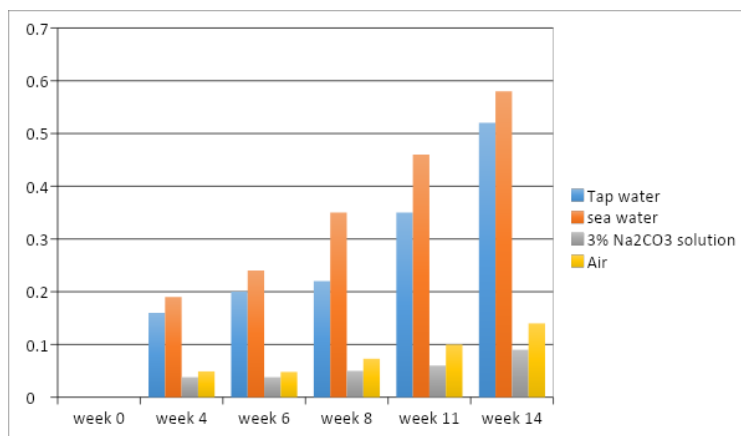


Figure 7: % Weight loss in mild steel samples in different corrosive medium

Table 2: Weight difference of mild steel samples

	3% Na ₂ CO ₃ solution	seawater	Tap water	Air
week 0	-	-	-	-
week 4	0.038%	0.19%	0.16%	0.049%
week 6	0.038%	0.24%	0.2%	0.048%
week 8	0.05%	0.35%	0.22%	0.073%
week 11	0.06%	0.46%	0.35%	0.10 %
week 14	0.09%	0.58%	0.52%	0.14%

On the basis of the data shown in table 2, it becomes crystal clear that the rate of mild steel corrosion occurs more in seawater, followed by tap water. In the case of air as a medium, the rate of corrosion was lower as compared to that observed in tap water. This table also shows that the change in weight of mild steel samples was seen much more when seawater acts as a medium, during the fourth week, the weight difference of the submerged mild steel sample in seawater was found to be equal to 0.19%. After this, the weight starts decreasing until the weight difference comes equal to 0.58% in the fourteenth week.

When tap water is the medium, the weight difference comes to be equal to 0.16% in the fourth week; then, the weight decreased until the weight difference arrived at 0.52% in the fourteenth week. It has been noticed that the weight difference between each week was less in the case of Na₂CO₃ solution, where the weight difference was observed to be 0.038% in the fourth week then arrived at 0.09% in the fourteenth week. In the case of the mild steel sample that was hanged in the air, the weight difference was found to be equal to 0.049% in the fourth week and becomes 0.14% in the fourteenth week. The results were also analyzed after applying different coatings on the mild steel samples for corrosion prevention. In the starting, the weight of the sample was 89.68 g.

In table 3 and figure 8, weight loss of mild steel sample coated with the Sodium Bicarbonate paste has been investigated for nine weeks. From the data obtained, it is clear that after completion of nine weeks, the weight loss decreased that is 89.68-gram, 89.63 g, 89.58 g, 89.51 g, and 89.48 g, from starting to ninth week respectively. So, for a better understanding, the values obtained have been translated into a diagram form (figure 8), showing weight loss with increasing time.

Table 3: Weight difference of mild steel coated with the Sodium Bicarbonate paste

	Weight difference of mild steel coated with the Sodium Bicarbonate
Week 0	-
Week 3	0.05 %
Week 6	0.13 %
Week 8	0.17 %
Week 9	% 0.2

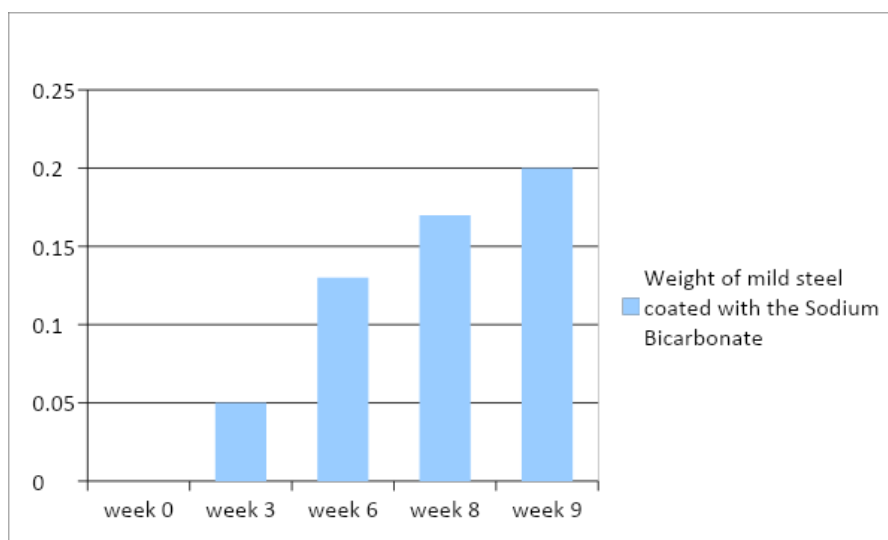


Figure 8: Weight difference of mild steel coated with the Sodium Bicarbonate paste

Thus, figure 8 shows the difference in weight between each week. After the mathematical calculations, Table 3 shows that after completion of the nine weeks, the weight difference of mild steel samples coated with the Sodium Bicarbonate paste increased to 0.05 %, 0.13 %, 0.17 %, and 0.2%, respectively. So, it is a bar diagram showing an increase in the mild steel weight for nine weeks and thus gives a positive relationship between the duration of mild steel coated with the Sodium Bicarbonate paste and the weight. The results also show that the change in weight between each week time was very small

and this indicates that the Sodium Bicarbonate paste helps in reducing the mild steel corrosion, but the weight difference starts increasing significantly from the eighth week, so it can be said that the coating efficiency decreases with the increase in time.

Table 4: Weight difference of mild steel coated with the aluminum paint

Medium Corrosive weight(g)	Air	3% of Na ₂ CO ₃ solution	Seawater	Tap water
	82.65	81.99	82.43	82.92

Table 4 and fig 9 shows the weight loss of mild steel coated with Aluminum paint (without inhibitor) in different corrosive medium. It is clear from the table that after seven weeks the weight of the mild steel coated with Aluminum paint (without inhibitor) decreased to 82.92 g, 82.90 g, 82.89 g, and 82.87 g, respectively in the tap water, in seawater the weight of coated mild steel decreased to 82.43 g, 82.39 g, 82.37 g and 82.33 g respectively whereas in 3% of Na₂CO₃ solution the weight of coated mild steel decreased to 81.99 g, 81.98 g, 81.98 g and 81.97g respectively. The weight of the coated mild steel sample that was hanged in the air decreased to 82.65 g, 82.65 g, 82.64 g, and 82.63 g, respectively. From figure 9, it has been noticed that the highest rate of weight loss was observed in the seawater and tap water, whereas the lowest rate of weight loss in the mild steel was observed in 3% Na₂CO₃ solution and in the air medium.

Table 5: Weight difference of mild steel coated with Aluminum paint

Week	Air	3% of Na ₂ CO ₃ solution	Seawater	Tap water
Week 0	-	-	-	-
Week 3	0	0.01	0.04	0.02
Week 5	0.01	0.01	0.07	0.04
Week 7	0.02	0.02	0.012	0.04

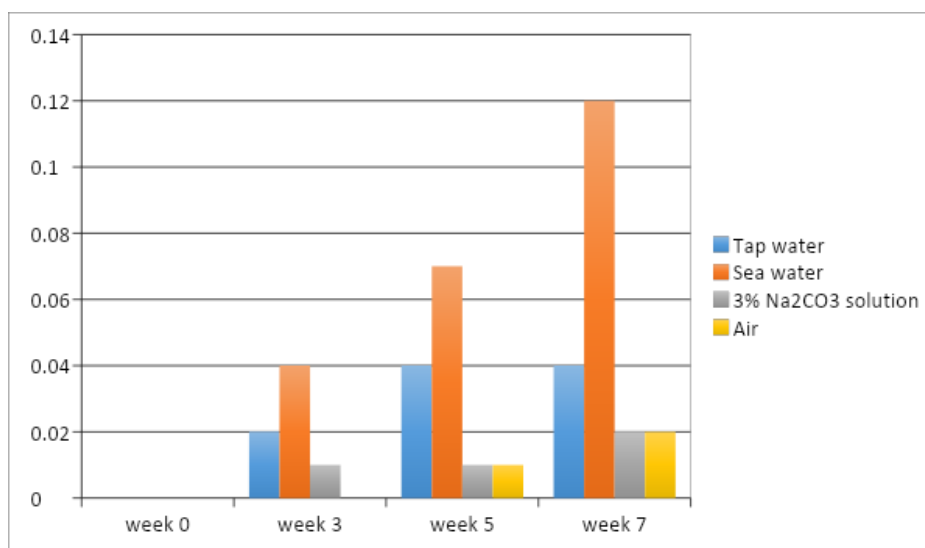


Figure 9: Weight difference of mild steel coated with Aluminum paint

Table 5 shows the difference in weight between each week and the other after the mathematical calculation. It shows that after completing seven weeks, the weight difference of mild steel samples coated with Aluminum paint (without inhibitor) increased to 0.02 %, and the weight difference was then fixed to 0.04 % in tap water. In seawater the weight difference increased to 0.04 %, 0.07 % and 0.012 % respectively. In a 3% Na₂CO₃ solution, between the third and fifth weeks, there was no change, where the weight difference was equal to 0.01%, and then it changes to 0.02% in the seventh week. The weight difference of coated mild steel sample that was hanged in the air did not change in the third week and equal to 0.01%, respectively, by 0.02% in the fifth and the seventh week. Fig 9 shows an increase in the mild steel weight for seven weeks. It is clear that a positive relationship exists between the time and the weight, the biggest change was observed in seawater, and the least change was in the air and 3% Na₂CO₃ solution.

Table 6: Weight loss of mild steel coated with aluminum paint and inhibitor

Corrosive media	Air	3% Na ₂ CO ₃ solution	Seawater	Tap water
Starting weight	85.74 g	83.57 g	81.43 g	85.05 g

Table 6, table 7 and figure 10, shows the weight loss of mild steel when coated with aluminum paint and inhibitor also in different corrosive medium. From table 6, it is clear that after seven weeks, the weight of mild steel coated with Aluminum paint and inhibitor has not changed in the third week, and afterward it decreased to 85.04 g, 85.03 g respectively in the tap water. In the case of seawater, the weight of coated mild steel decreased to 81.43 g, 81.42 g, 81.40 g, and 81.39 g in the respective weeks whereas, in the case of 3% of the Na₂CO₃ solution, the weight of coated mild steel remained constant in

all seven weeks analysis. The weight of the coated mild steel sample that was hanged in the air, in the third and the fifth week, no change was observed, whereas the weight decreased from 85.74 g to 85.73 g in the seventh week. From figure 10 also, it must be taken into account that the highest rate of weight loss was observed in seawater and tap water, whereas the lowest rate was observed in the air as the corrosive medium.

Table 7: Weight difference of mild steel coated with Aluminum paint and inhibitor

Week	Air	3% Na ₂ CO ₃ solution	Seawater	Tap water
week 0	-	-	-	-
week 3	0	0	0.01	0
week 5	0	0	0.04	0.01
week 7	0.01	0	0.05	0.02

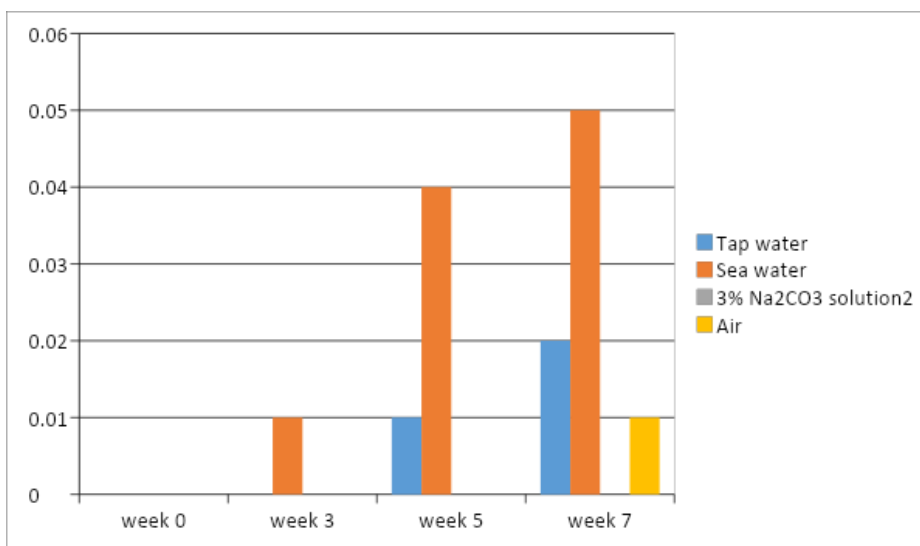


Figure 10: Weight difference of mild steel coated with Aluminum paint and inhibitor

So, all the results clearly indicate that the efficiency of the aluminum paint is greatly increased in the presence of ascorbic acid inhibitor.

CONCLUSION: On the basis of the experimental investigation done here, it was concluded that more weight loss of uncoated mild steel was in seawater that is equal to 80.39 g from 80.86 g and the lowest value was in 3% Na₂CO₃ solution that is equal to 78.68 g from 78.75 g. When coating was done on the surface of mild steel decrease in the weight was observed, and the weight loss of coated mild steel with Sodium Bicarbonate paste equals to 89.48 g from 89.68 g after nine weeks whereas when the aluminum paint was coated on the surface of the mild steel, the weight loss was observed to be equal to 82.87 g from 82.92 g, 82.33 g from 82.43 g, 81.97 g from 81.99 g and 82.65 g to 82.63 g in tap water, seawater, 3% Na₂CO₃ solution and air medium respectively. More studies on the corrosion protection was performed by coating the mild steel surface with aluminum paint along with ascorbic acid inhibitor, i.e., a green corrosion inhibitor and it was found that the weight loss data is-85.03 g from 85.05 g, 82.39 g from 82.43 g, no change in the weight and 85.73 g from 85.74 g in tap water, seawater, 3% Na₂CO₃ solution and air medium respectively. Thus, as the techniques used in this experiment are simple and a natural corrosion inhibitor has been used to study the corrosion rate, this work is very safe and eco-friendly

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