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# Development of Corrosion Resistance Coatings for Sea Water Pipeline

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***Abstract***
***The pipelines that are used for transporting sea water to desalination plants are made of expensive steel alloys. However because of the salt content in water and also other atmospheric factors this pipe undergoes severe corrosion problem. This causes pits and holes in pipe surface making it useless and lead to huge replacement cost of pipes. Hence a way to control corrosion is needed. In this project use of different coatings to overcome corrosion is tested experimentally. Five types of coatings namely epoxy, aluminum, enamel, rubber, and chrome are coated on the samples prepared from actual pipeline used in the plant and the experimental results and analysis are summarized for finding the best coating for reducing corrosion of pipes. Among the five different coatings tested the rubber and epoxy coatings resulted with minimum corrosion rate and weight loss.***

**Keywords: sea water pipeline, corrosion, epoxy, primer, enamel, rubber, chrome coatings.**

## I. INTRODUCTION

### *1.1 Overview of the project*

Water is the most important item that is needed to sustain life on earth. It is necessary for all living things. Sea water is especially put into use for oil and gas production. For this purpose it is need to transport this water by means of cement, plastic or metal pipes. There are special carbon steel pipes that are laid under the ground.

Corrosion is a damage or slow destruction of metal surface that occurs as a result of some chemical reaction with environmental factors. Environment factors like temperature, humidity, water and soil can act like corrosion agents (Fontana & Greene 1967). Because the salt water of the sea is transported through these pipes, this water contains salts. Water that contains salt can result in corrosion in inside surfaces of these pipes. Also because of the salts on the ground, air, moisture and other factors the pipes undergo corrosion on the outside as well. If the surface undergoes corrosion regularly it results in small holes or rough surface of the pipes. This reduces the lifetime of the pipe (Winston, 1985). Changing these pipes frequently is also not possible because of the high cost involved. Hence there is a need to develop some anti-corrosion coatings for these pipes. This will help to isolate the material of pipes from the water or any material that causes corrosion (Winston, 2015).

### *1.2 Project Scope*

The present work deals with the development of an anti-corrosion coating for the pipeline. The main objectives of the paper are 1. To conduct a study of corrosion problems that are related to sea water pipeline that is used for desalination plant.2. Analyze the corrosion problem 3. Develop corrosion resistant coatings for sea water pipeline.

Some of the advantages that this will provide are as given under:

a) The anti-corrosion coating will act like a barrier between the water surface and pipe surface. This will prevent the sea water to come in direct contact with the metal pipe surface. This will prevent corrosion.

b) This will improve the life time of the pipeline. The pipeline when coated with anti-corrosion coating will not corrode easily and so it can be used for a long time with the same efficiency.

By using a proper mechanism for anti-corrosion coating, the following advantages can be seen in the long run.

a) The corrosion of pipeline is prevented;

b) Lifetime of pipeline is increased considerably;

c) The money needed to change pipeline frequently is saved.

## 2. INTRODUCTION

The harmful effects of corrosion on the material are discussed along with some of the ways by which it can be prevented. Different types of anti-corrosion coatings are also discussed briefly.

### *2.1 Corrosion of the pipelines carrying sea water*

Many factors need to be taken into account regarding the corrosion of sea water pipes. The simple measure is rate of general or localized corrosion that occurs under steady flow of water. Sometimes the water may be stagnant or move very slowly. This results in corrosion at the crevices or some deposits or pitting. The corrosion largely varies with the change in composition of sea water. With the changes in saline content (salt content), oxygen content, the amount of suspended materials in the water and pollutants may affect the rate of corrosion of the pipes.

Three important factors that are responsible for corrosion due to sea water are as follows (Yari, 2015):

a) Composition of chloride (salinity): one of the most aggressive substances in sea water is chloride ions. It is generally the amount of salt in water.

b) Oxygen: The amount of oxygen in sea water also affects the corrosion rate of metal pipes.

c) Temperature: temperature has an impact on the amount of oxygen and hence influence the corrosion rate.

TABLE 1 TYPES OF DIFFERENT CORROSION INVOLVED IN PIPELINES

| Type of Corrosion | Materials and systems involved in pipeline |
|---|---|
| Pitting and Crevice Corrosion | 316L distillate pipeline due to dissolved $co_2$ , $o_2$ , high cl |
| Impingement | mild steel/cast iron/epoxy lined pipeline due to water hammer or turbulence |
| general corrosion and pitting | 316L Vent pipeline due to non-condensable gas attack |
| Rebar Corrosion | CCP or PCP product water pipe due lines. General corrosion due to the formation of electrochemical cells between rebar and air/$O_2$ , $CO_2$ , through concrete cover. |

Source: (Malik, Ahmad, & Anjidani, 1992)

*2.2 Effects of Corrosion on pipeline*

Some of the harmful effects of corrosion in pipeline carrying sea water can be summarized as follows:

a) The thickness of the pipeline material gets reduced considerably. This leads to a loss in strength and sometimes structural failure or breakdown.

b) Contamination of water with other sewage or any other water.

c) There can be some mechanical damage to valves or pumps. There could also be a blockage of pipes as a result of solid corrosion products.

Corrosion means the deterioration and degradation of a material due to a reaction with its environment. That means changing the physical properties of the materials such as Iron, plastics, concrete, wood and etc. but generally the iron is one of the most and easily corrodible metals. Pipe materials that contain iron are getting easily corrosion by reacting with air. When the air is having more humidity, the pipe material will react with O2 and corrosion effect will be more. The material of the pipe will become weak due to corrosion and thereby reduce strength of materials.

Corrosion can be prevented by alloying metals that form naturally protective passive films but these alloys are usually expensive. Hence the corrosion control systems are used by applying chemicals, paintings, coatings etc.

The following figure shows the corrosion on a cast iron pipe after a long time.

Figure 1: corrosion inside a cast iron pipe after 110 years (Gonzalez & Encalada, 2010)

*2.3 Prevention of corrosion due to sea water*

Some of the methods that can be used to prevent corrosion in pipelines is discussed below:

Dehydration: Free water is the most common reason for corrosion, dehydration is the most common method to control it. However it is not possible for pipelines carrying sea water (Baker, 2008).

Inhibitors: These are certain chemicals that are added to the pipelines that reduce the corrosion rate. They either cling or react to metal surface and form a thin film that protects it from corrosion. Some commercial products are also available but their choice depends on many factors like availability, cost and other environment factors (Baker, 2008).

Coatings: They can be used on some gas transmission pipelines. They improve product flow by reducing drag and also eliminate dust.

Buffering: Buffering agents often change the chemical composition of fluids. However because of the limitation in covering the entire surface of pipe it is not very effective (Baker, 2008).

*2.4 Anti-corrosion coatings*

Many different types of coatings can be used to reduce corrosion. For this purpose materials used are epoxy, aluminum primer, enamel paint, rubber and chrome. More details are provided in the following sessions.

(Guan, 2001) Gives a solution of using 100% solid polyurethane coatings in pipes to reduce corrosion. Experiment results shows that it has a high application rate than epoxy systems thereby giving it an advantage over other systems.

TABLE 2: THICKNESS SPECIFICATIONS FOR APPLICATION OF 100% POLYURETHANE COATINGS

| Substrate Type | Internal Application | External Application |
|---|---|---|
| Steel | 20 mils (500 microns) – normal | 20 mils (500 microns) – normal<br>50 mils (1250 microns) - slip bore |
| Ductile iron | 40 mils (1000 microns) | 25 mils (625 microns)<br>50 mils (1250 microns) – slip bore |
| Reinforced concrete | 60 mils (1500 microns) | 40 mils (1000 microns) |
| Pre-stressed concrete cylinder | 25 mils (625 microns) | 30 mils (750 microns) |

Source: (Guan, 2001)

The performances of coatings are dependent on a number of factors. These include surface preparation i.e., how well is the surface prepared before application of coating, the thickness of the film, the temperature, handling damages if any and many more. The longevity of the coating is dependent on these factors.

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TABLE 3: PERFORMANCE TESTING OF COATING MATERIALS

| Performance Testing Data | Solvent Amine Based Epoxy | 100% Solids Epoxy | 100% Solids Elastomeric Polyurethane | 100% Solids Rigid Polyurethane | Cement-Mortar |
|---|---|---|---|---|---|
| Abrasion (ASTM D4060 1Kg, CS17, 1000 cycles) | 122 mg loss | 183 mg loss | 15 mg loss | 50 mg loss | 1500 mg loss |
| Adhesion (ASTM D4541) | 1280 psi (8.8 Mpa) | 925 psi (6.4 Mpa) | 1000 psi (6.9 Mpa) | 2000 psi (13.8 Mpa) | 0 psi (0 Mpa) |
| Cathodic Disbondment (ASTM G95; 3% NaCl, -1.5 volts, 30 days, 23°C) | 15 mm avg. | 15 mm avg. | 30 mm avg. | 8 mm avg. | Complete Disbondment |
| Chemical Resistance (ASTM D714, 1000 hours) | Pass (20% $Na_2SO_4$, 3% NaCl, 3% $H_2SO_4$, gasoline) | Pass (20% $Na_2SO_4$, 3% NaCl, 3% $H_2SO_4$, gasoline) | Pass (20% $Na_2SO_4$, 3% NaCl, 3% $H_2SO_4$, gasoline) | Pass (20% $Na_2SO_4$, 3% NaCl, 3% $H_2SO_4$, gasoline) | Pass (20% $Na_2SO_4$, 3% NaCl, 3% $H_2SO_4$, gasoline) |
| Flexibility (ASTM D522) | Failure at 180° over a 2" (5.08 cm) mandrill | Failure at 180° over a 2" (5.08 cm) mandrill | Pass at 180° over a 2" (5.08 cm) mandrill | Pass at 180° over a 2" (5.08 cm) mandrill | Failure at 180° over a 2" (5.08 cm) mandrill |
| Impact Resistance (ASTM G14) | 38 in.lbs (4.3 J) | 15 in.lbs (1.7 J) | 80 in.lbs (9.0 J) | 50 in.lbs (5.7 J) | 2 in.lbs (0.2 J) |
| Salt Spray Resistance (ASTM B117) | Pass at 1000 hours | Pass at 1000 hours | Pass at 1000 hours | Pass at 1000 hours | Pass at 1000 hours |
| Water Absorption (ASTM D570, 50°C, 48 hours) | 2% | 2% | 6% | 2% | 7% |

Source: (Guan, 2001)

## 3. EXPERIMENTAL SET UP AND METHODOLOGY

This section presents the details of the experimental set up that was used. The first step in carrying the experiment is collecting all the materials and parts that are needed. Then a design is made. Experiment is carried out and the results are noted.

### *3.1 Sample preparation*

The samples for carrying out the corrosion test are prepared as per the following step by step procedure.

#### *3.1.1 Pipe line samples*

For the purpose of this assignment three parts of a carbon pipeline were split into half by using a grinder machine. The total length of sample was 100mm.

Figure 2: Carbon steel Pipeline

#### *3.1.2 Cutting of Samples*

- For purpose of experiment 6 pieces each of 100 mm are required
- The pieces are then cut from top to bottom vertically
- Smoothening of sharp edges done by using a grinder

Figure 3: Cutting process of carbon steel samples

#### *3.1.3 Preparation of the surface*

For preparing the surface a Copper Slag grit blasting is used that has a size of 0.4 to 1.2 mm with 6-7 bar of air.

Figure 4: Surface preparation.

Make sure that the surface is free from pits and other abnormalities. This is shown in the following figure.

Figure 5: Surface free from pits.

#### *3.1.4 Coating of Samples:*

The next step is coating of the samples. The samples are coated on both sides. Total 5 samples are coated with different materials while one sample is left uncoated. Thinner was used before starting to coat any of the samples.Six Samples are available under the test Epoxy, aluminium, Enamel, Chrome, Rubber and the uncoated sample.

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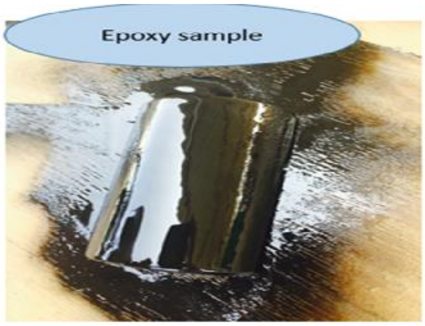


Figure 6: carbon steel pipe sample coated with epoxy.


Figure 7: carbon steel pipe sample coated with chrome.


Figure 8: carbon steel pipe sample coated with aluminium.

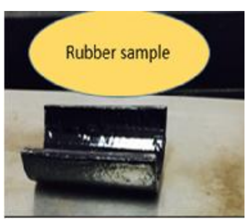


Figure 9: carbon steel pipe sample coated with Rubber.


Figure 10: carbon steel pipe sample coated with Enamel.

### *3.2 Experiment setup*

Five different types of coatings are applied on carbon steel samples and one sample without coating. The samples are made to hang with the help of metal wires. Air-pump is used to pump air into brine sea water so that the corrosion starts. The box is filled with brine sea water that has a conductivity of more than 90000 µs. Then check weight loss every week up to one month by electronic balance and record reading

Figure 11: samples are hanging as vertical direction with leave a space between all .

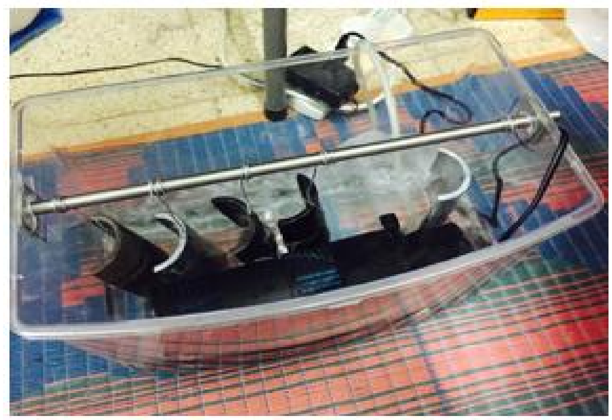

Figure 12: The box is filled by brine sea water to cover half level of the samples.

## 4 RESULTS AND DISCUSSIONS

All the samples are subjected to surface roughness, hardness and corrosion rate testing and the method of testing with the results are described below.

### *4.1. Surface roughness test*

Surface roughness test is an important test for satisfactory operation of the pipe surfaces with coating. Machined surfaces show smooth to the naked eye, but it shows quite rough at the microscopic levels. Now computer program is used with reader tool in order to check root mean square value of metallic surface roughness (Rq). It is obtained as

$R_a = \frac{1}{1}\int_0^1 |Y(x)|dx$ ,where Y(x) is the profile ordinates of roughness profile.

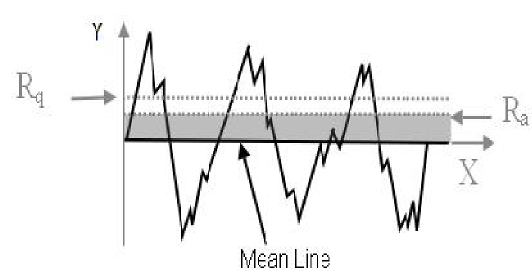


Figure 14 Roughness profile

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Mean roughness depth (Ra) is a section of the standard length which is sampled from the mean line on the roughness profile. The distance between the peaks and valleys of the sampled line is measured in the y direction. then, the average peak is obtained among five tallest peaks (Yp), and five lowest valleys(Yv). It is expressed in micrometer

$$R_a = \frac{|Yp1+Yp2+Yp3+Yp4+Yp5|+|Yv1+Yv2+Yv3+Yv4+Yv5|}{5}$$

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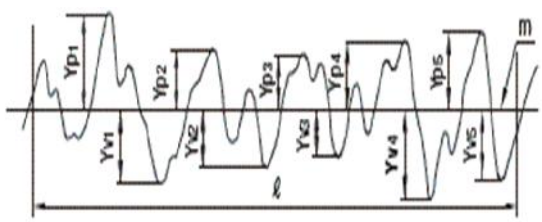


Figure 15 Roughness profile

TABLE 4: RESULTS OF SURFACE ROUGHNESS TEST VALUE

| surface roughness test | | |
|---|---|---|
| sample name | Rz (um) | Rq (um) |
| epoxy coating | 1.24 | 0.48 |
| chrome coating | 1.9 | 0.35 |
| rubber coating | 25.66 | 6.86 |
| aluminum coating | 4.45 | 1.33 |
| enamel coating | 7.38 | 1.77 |
| without coating | 41.22 | 12.78 |

*4.2. DFT (Dry film Thickness)*

Thickness of the film is tested by measuring using electrometer device. This measurement is important to know the thickness of coating exactly on sample surface area. All the samples were coated with uniform coating thickness of 50 micrometers and it was cross checked with electrometer coating thickness gauge.

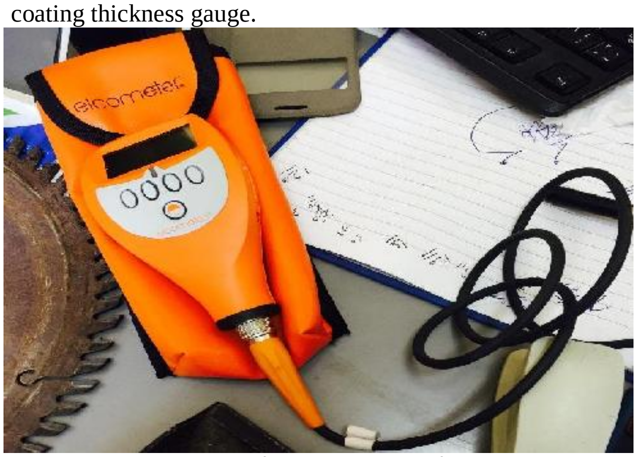


Figure 16: DFT (dry film thickness) device for measure thickness of coating.

*4.3. Weight loss of samples*

The initial weights of all the samples are measured using an electronic balance. Weights of all samples are measured at the end of each week for a span of 1 month. The weight values after exposure to the corrosion environment are recorded in Table 5 given below. The results clearly indicate that the maximum weight loss occurs for samples without coating and minimum for rubber coating. Weight loss for epoxy and enamel coating are also closer to that of rubber coating.

TABLE 5: WEIGHT LOSS AFTER ONE MONTH

| weight of samples | | | | | | |
|---|---|---|---|---|---|---|
| samples name | Initial weight (g) | reading after 1 week (g) | reading after 2 week (g) | reading after 3 week (g) | reading after month (g) | weight loss per month (g) |
| without coating | 343.2 | 342 | 340.6 | 339.4 | 338.1 | 5.1 |
| epoxy coating | 324.2 | 324.05 | 323.89 | 323.72 | 323.59 | 0.61 |
| chrome coating | 373 | 372.78 | 372.55 | 372.3 | 372.07 | 0.93 |
| aluminum coating | 361 | 360.82 | 360.62 | 360.41 | 360.22 | 0.78 |
| rubber coating | 358 | 357.9 | 357.7 | 357.6 | 357.4 | 0.6 |
| enamel coating | 344 | 343.84 | 343.7 | 343.56 | 343.38 | 0.62 |

*4.4. Hardness testing*

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter.

Hardness testing by Rockwell device chose scale no. 3 C, with diamond indentor, load 150 kgf application for hard cast iron, pearlitic malleable iron , steel, deep case hardened steel and titanium. Four readings were taken for each sample and the average value is considered as the hardness value for each sample.

TABLE 6: RESULTS OF HARDNESS TESTING

| hardness testing | | | | | |
|---|---|---|---|---|---|
| samples name | reading 1 | reading 2 | reading 3 | reading 4 | average |
| epoxy coating | 63 | 78.2 | 60.2 | 77.5 | 69.725 |
| chrome coating | 59.8 | 72.5 | 78.2 | 76.1 | 71.65 |
| aluminum coating | 68.6 | 72.9 | 62.6 | 77.5 | 70.4 |
| rubber coating | 62.8 | 76 | 66.7 | 65.1 | 67.65 |
| enamel coating | 70.4 | 69.5 | 71.6 | 67.9 | 69.85 |
| without coating | 65.1 | 62.4 | 70 | 64.9 | 65.6 |

*4.5. Calculating the corrosion Rate:*

The corrosion rate of all the samples is calculated by using the following formula:

$$R_{corr}\ (mm/yr) = (Weight\ loss\ (mg) / Density(g/cm^3) \times Area\ (cm^2) \times Time\ (hrs)) \times 87.6$$

The corrosion rate of a sample is calculated using the above formula where the corrosion rate is calculated in terms of mm/year. The corrosion rates for all the samples are provided in Table 7 with maximum corrosion rate for the sample without coating and minimum for the epoxy coating. The samples with rubber coating and enamel coating also possess corrosion rate values very close to epoxy coating.

TABLE 7: CORROSION RATE (MM/Y)

| corrosion rate | |
|---|---|
| samples name | reading (mmpy) |
| without coating | 1.05 |
| epoxy coating | 0.12 |
| chrome coating | 0.191 |
| aluminum coating | 0.16 |
| rubber coating | 0.123 |
| enamel coating | 0.127 |

## 5 CONCLUSION

From the experiments that have been carried out and looking at the results from the previous sections it is clear that coating the pipes does reduce corrosion of pipes thus improving their life. Out of the five types of coatings tested it was found that the best was epoxy coating that had the best protection from corrosion by giving the lowest corrosion rate. The enamel paint and rubber coating were also as good as epoxy coating. Coating of sea water pipe lines improves the life and efficiency of the system. However, it must be noted that relying solely on liners or coatings may not be prudent since it is very unlikely that the problems associated with each can be remedied. Many operators who do use liners or coatings also apply additional preventive measures. Multilayer coatings can be tested for anticorrosion performance compared to single layer coating as future work. Addition of nano particles to reduce corrosion rate also can be tested for corrosion resistance.

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