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Corrosion Behaviour of a Low Carbon Steel Piping Exposed to Different Water Conditions

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Abstract: Although low carbon steel piping is broadly used due to its strength and wide availability, extensive exposure to water significantly affects its susceptibility to corrode. The main objective of this research is to investigate the corrosion behaviour of low carbon steel piping when exposed to different water conditions, which are seawater, lake water, and tap water. Immersion corrosion test was performed on low carbon steel piping samples to obtain corrosion rate based on the samples' weight loss. Lake water produced the greatest weight loss at 0.24366 g, and the fastest corrosion rate, which is 0.4069 mmy at the end of test. The results show that this is due to the lake water's qualities, especially the high level of dissolved oxygen (DO) of 8.59 ppm and its pH of 6.13 being the most acidic out of all the samples. Hence, these two parameters are significant in determining the rate of corrosion for low carbon steel piping exposed to water.

Keywords: Low Carbon Steel, Immersion Test, Corrosion Rate

1. Introduction

Corrosion has been known to cause irreversible adverse effects to both the inner and outer walls of pipeline [1]. The inner and outer walls of the pipeline are both subjected to corrosion whether they are exposed to the same or different type of environments. Corrosion also results in additional costs being spent and poses significant risks to human life and safety [2]. Therefore, it is important to recognise the factors that influence corrosion to minimise its ramifications on the walls of pipeline.

The rate of corrosion varies according to atmospheric conditions or environment. When steel piping is submerged in water, the parameters which affect its corrosion may include pH level, oxygen content, water temperature, the presence of corrosion inhibitors, and chloride levels. Immersion corrosion loss of low carbon steels can be affected by water pollution in a variety of ways [3]. One of the various ways it could be affected is through the bulk water's reduced content of dissolved oxygen (DO). Additionally, sulphate-reducing bacteria (SRB) is also known to influence corrosion behaviour in different types of metals including steel [4].

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Corrosion processes modify the physical characteristics and mechanical behaviours of metals and metal alloys, in addition to their chemical properties [5]. Low carbon steel pipes are known to be predisposed to corrosion, especially over a long period of time when exposed to water. Different types of water conditions exhibit multiple different water constituents such as pH, salinity, and levels of dissolved oxygen, and exposure of low carbon steel to them may result in different corrosion behaviours. In the long run, corrosion of steel pipes leads to contamination of water systems and cause health hazards along with onset water systems failure. The objectives of this study are to identify the corrosion rate of the low carbon steel piping submerged in different types of water conditions and determine the characteristics of low carbon steel piping under exposure to water.

2. Materials and Methods

2.1 Materials

The low carbon steel piping utilised in this project was acquired according to the length needed to produce one piping sample for each of the different water conditions. The piping chosen is 27 millimetres in diameter and thickness of 1.6 millimetres with the consideration of beaker size for immersion test and ease of storage. For the preparation of the water samples, the tap water and lake water are obtained from nearest possible source. Tap water sample is obtained directly from the tap located near Metallurgy Lab, UTHM. Sample for the lake water is collected from the lake located right in front of the G3 block's building in UTHM. On the other hand, the seawater utilised in this research is obtained from the shore of the nearest sea, which is located at Sg. Lurus, Senggarang.

2.1 Water quality test

Water quality test was employed on all of three types of water conditions. Parameters of water quality which are total dissolved solid (TDS), dissolved oxygen (DO) content, salinity and pH level were measured using a laboratory multi-meter. Corrosion rate decreases as pH rises, implying that corrosion rate is proportional to level of acidity of a substance [6]. Meanwhile, dissolved oxygen can oxidise dissolved ions into insoluble forms and damage the protective hydrogen film which can develop on many types of metals.

2.3 Immersion test

Immersion corrosion test was performed to evaluate the piping samples' responses to the established material and immersion conditions. Essentially, the test is employed to determine weight loss of the piping due to corrosion when continuously exposed to water. In this project, the piping samples were immersed in seawater, lake water, and tap water each in a span of four weeks. Every week, the samples go through the process of cleaning, drying, and weighing to measure their weight before and after the immersion process. Afterwards, the rate of corrosion is obtained by calculation of weight loss over time with the consideration of the sample's density and exposed area as demonstrated in the following equation:

$$CPR = \frac{\mathrm{W} \times \mathrm{k}}{\rho \times \mathrm{A} \times \mathrm{t}} \qquad \text{Eq. 1}$$

3. Results and Discussion

At the end of the immersion test, the results for percentage of weight loss and corrosion rate for the low carbon steel piping samples which were submerged in seawater, lake water, and tap water are tabulated and compared. The piping samples' surface were observed using optical microscope to detect any visible deterioration due to corrosion. On the other hand, microstructure of the piping was examined using scanning electron microscope (SEM).

3.1 Properties of water samples

The parameters which are included in water quality tests for the samples are the salinity, pH, total dissolved solids (TDS), and level of dissolved oxygen (DO). These factors are the major aspects which vary for each of the water conditions. These factors also influence the effects of corrosion on the samples, as well as the rate of corrosion. Table 1 describes the parameters for the samples of seawater, lake water, and tap water which were utilised in this research.

Table 1: Results of pH, salinity, TDS, and DO tests on water samples

Water condition	pH	Salinity (ppt)	Total dissolved solids (ppm)	Dissolved oxygen (ppm)
Seawater	6.85	31.3	4450	6.02
Lake water	6.13	0.07	279	8.59
Tap water	6.46	0.08	116	6.73

In terms of pH, lake water is the most acidic due to its value being the lowest. More acidic waters with low pH speed up corrosion by supplying a lot of hydrogen ions. The increase of hydrogen ions in the water to react with the electrons increases the likelihood of corrosion. On the other hand, water corrosivity decreases beyond a salinity of 3 percent because corrosion rates tend to rise as water conductivity rises [7]. In respect of the levels of dissolved oxygen, the most crucial factor in metal pipe corrosion is DO, and when the levels of DO rise, uniform corrosion also becomes dominant on carbon steel [8,9].

3.2 Immersion test results

The immersion test involved three samples of low carbon steel piping, where each of the sample was immersed in three different water conditions, which are seawater, lake water and tap water. Figure 1 shows the set-up of immersion test with beakers containing the piping and water samples in the laboratory. The samples' weight was recorded once every week, over a period of four weeks, or 28 days. The results obtained were then be utilised to calculate the rate of corrosion for each sample.

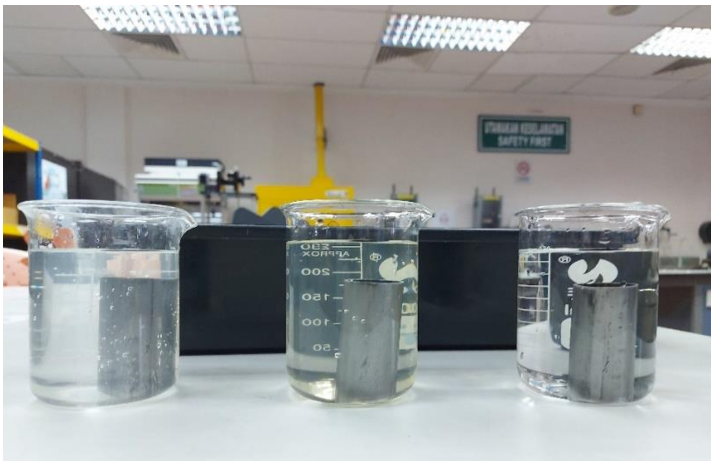


Figure 1: Immersion corrosion test set-up with piping and water samples

The samples' weight loss at the end of each week were obtained after drying and then cleaning the samples using a bristle brush and acetone solvent. Afterwards, the samples were weighed using a digital balance. Over the span of 28 days, the piping samples continuously experienced weight loss, albeit at different rate per week. After the immersion test was carried out, the low carbon steel piping sample immersed in lake water suffered the highest amount of weight loss, followed by tap water, and seawater. In terms of weight loss percentage, the results are directly proportional to the total weight loss as shown in Figure 2.

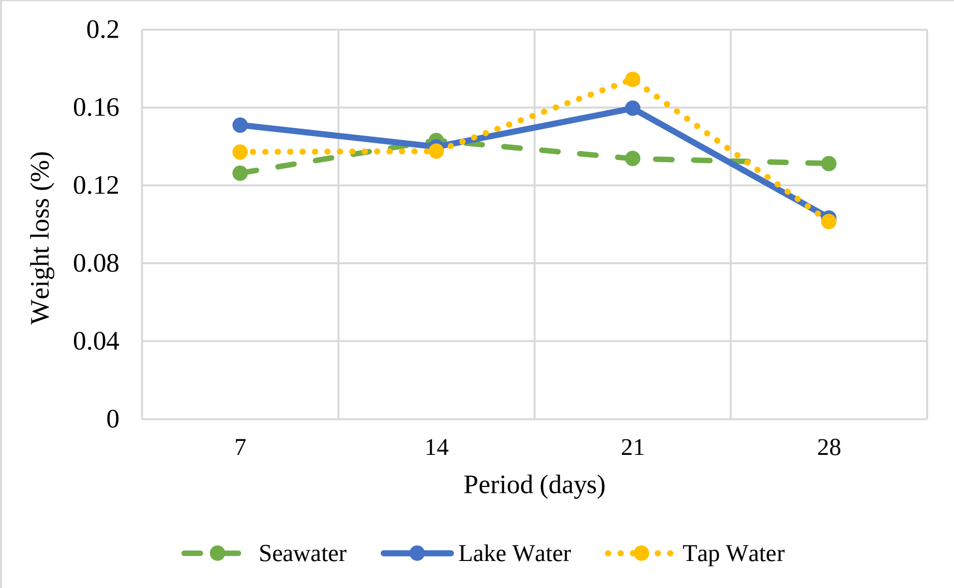


Figure 2: Weight loss percentage of piping samples over time

The results obtained for corrosion rate show an increasing trend in the first 21 days, and eventually a decreasing trend at the end of the immersion test for all three of the water conditions. The inclination for rate of corrosion matches the weight loss of samples which has been previously observed, in terms of their rise or decline. The sample immersed in lake water exhibited the highest rate of corrosion from the first week to the fourth week in comparison to the other samples. Figure 3 illustrates the piping samples' rate of corrosion over time.

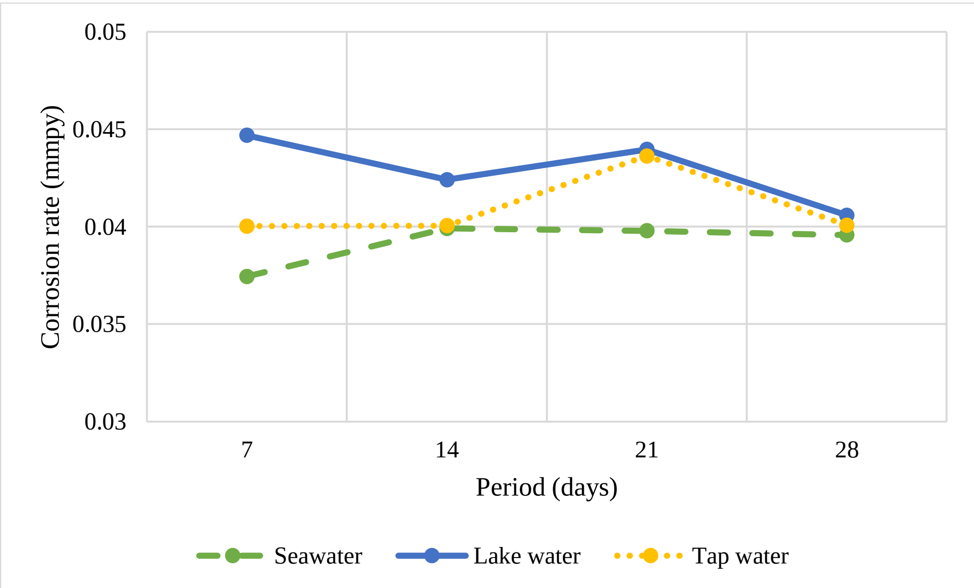


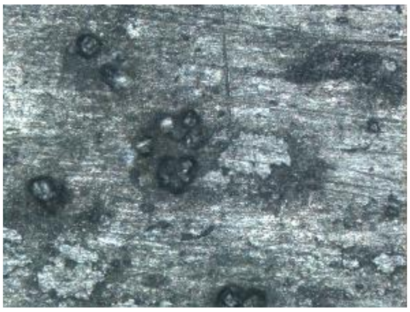
Figure 3: Corrosion rate of piping samples over time

3.3 Surface and microstructure observations of samples

Surface observations for the low carbon steel piping samples are performed using the optical microscope (OM), while microstructure observations are completed using scanning electron microscope (SEM). The observations allow for a close examination of the samples' surface in order to further analyse the corrosion behaviour. Optical microscope observations revealed several consequences toward exposure of all three of the piping samples to the different water conditions. Pitting corrosion occurred on all of the samples' surface.

Figure 4 reveals the samples' surface at 100x level of magnification under the OM. The sample immersed in seawater showed a consistent end result in terms of distribution of corrosion effects on its surface. Rust in form of brown coloured specks and small sized pits were observed on its surface. Overall, the sample may be considered to have experienced general corrosion. Sample immersed in lake water on the hand showed slightly bigger sized, and darker coloured pits. Other than pitting corrosion, the sample immersed in tap water showed bright discolouration on a small part of its surface.

(a) Seawater



(b) Lake water

(c) Tap water

Figure 4: Surface of samples after corrosion attack under optical microscope

Microstructure observations on the samples were performed using scanning electron microscope (SEM) before and after the immersion test. This step was completed to further analyse the changes on the sample's microstructure due to the process of corrosion. The level of magnification initiated on the samples was at 200x. The micrographs revealed distinct perspective and visual on the microstructure which allowed for a precise analysis and comparison of the piping samples before, and after corrosion attack.

Figure 5 demonstrates the micrographs of the piping sample under SEM at 200x level of magnification before the immersion test was performed. SEM micrograph of the sample shows microstructure of the sample after it has been sanded and polished. As illustrated in Figure 5, the polished low carbon steel's surface was smooth with some minor surface scratches and roughness that were brought on by the sanding process of the prepared samples.

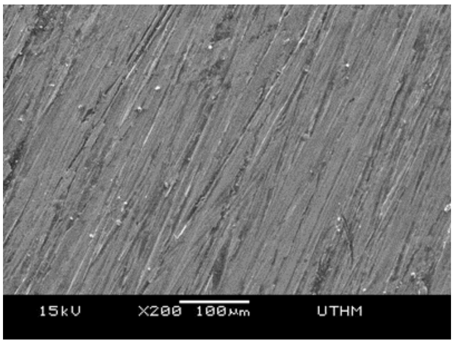
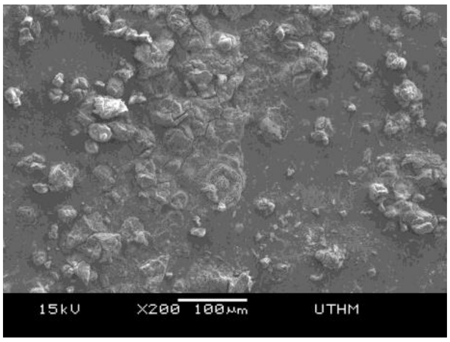
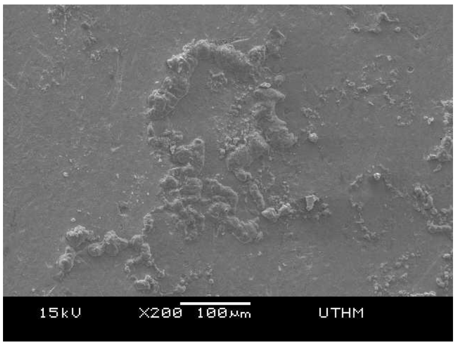
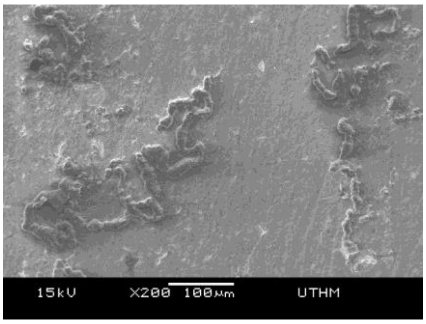


Figure 5: Micrograph of sample at 200x magnification level before immersion test





(a) Seawater (b) Lake water



(d) Tap water

Figure 6: Micrographs of samples at 200x magnification level after immersion test

Figure 6 displays the piping samples' microstructure after immersion test under SEM. Corrosion products which are scattered on the deteriorated surface of the sample were observed through the SEM micrographs of piping immersed in seawater. The low carbon steel sample which was immersed in lake water exhibited localised corrosion, and corrosion product along with some cracking can be detected on its surface. Corrosion products on tap water immersion sample manifested on the surface in branch-like pattern. The formation of corrosion products also seems to be tube-like in shape and are distributed in different directions across the surface.

4. Conclusion

Based on the findings of the present study as well as earlier reports, it is well-established that the corrosion behaviour for each of the piping samples differed from each other due to the difference in properties of the water samples. Lake water immersion produced the highest rate of corrosion and weight loss, followed by tap water and seawater. Tests were also performed on the water samples to obtain the parameters of water quality, which are pH, salinity, total dissolved solid (TDS), and dissolved oxygen (DO). The seawater sample had the highest value for every single one of the mentioned parameters, except DO. Water sample with the highest value of DO was lake water, which produced the fastest corrosion rate. Out of all the water quality parameters observed in this study, two parameters are significant in determining the rate of corrosion for low carbon steel piping exposed to water which are the pH and levels of DO. Nevertheless, it is difficult to ascertain the corrosion behaviour and rate of corrosion for when all the parameters are combined with completely varied values.

Recommendations for the development and improvement of future research includes placing the beakers for the immersion corrosion test in an environment which is consistent in terms of temperature and humidity. Additionally, increasing the amount of water samples and varying the locations and days or time in which they are taken would allow for a more accurate representation of water quality parameters. Finally, observing a longer period for the immersion tests may allow for the examination of more changes on the piping samples due to corrosion.

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