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REVOLUTION (IJIREV)www.ijirev.comAN EXPERIMENTAL ANALYSIS OF MILD STEEL
CORROSION IN DIFFERENT WATER SOURCESSalihah Tan Shilan^{1*}, Nor Zaity Zakaria²¹Pusat Asasi STEM, Universiti Malaysia Terengganu, Malaysia salihah.shilan@umt.edu.my <https://orcid.org/0009-0004-9987-277X>²Department of Foundation and Diploma studies, College of Computing and Informatics, Universiti Tenaga Nasional, Malaysia zaity@uniten.edu.my <https://orcid.org/0000-0001-6050-9499>

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DOI: 10.35631/IJIREV.826027**Abstract:**

The corrosion behaviour of iron rods in tap water, RO water, Spritzer mineral water, Desa mineral water and sea water for seven weeks was studied. Mass, length, diameter and BOD were measured weekly. The corrosion rates were determined by weight loss using the ASTM G31 method. The results indicated the effect of water chemistry on dimensional changes and corrosion behaviour. RO water showed the lowest corrosion tendency. Seawater due to the dissolved salts were higher with the corrosion related changes. The result showed significant differences among the responses to water-media.

Keyword:

Corrosion, Metal Rod, Mass Loss, Material Degradation



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Introduction

Corrosion is a naturally occurring electrochemical process that causes the deterioration of metallic materials through reactions with their surrounding environment. Iron and steel are among the most commonly used engineering materials due to their excellent mechanical properties, availability, and relatively low cost. Despite these advantages, iron is highly susceptible to corrosion, particularly when exposed to aqueous environments containing dissolved oxygen, salts, and other corrosive agents (Revie & Uhlig, 2011). The corrosion of iron produces rust, which reduces the strength, durability, and service life of metallic structures and components (Fontana, 2005).

Many industries have been affected by corrosion which including construction, transportation, marine engineering, and water distribution systems. Studied by Schweitzer (2010), the causes of worldwide substantial economic losses which due to equipment damage, increased maintenance costs, and reduction operational efficiency is corrosion. Therefore, it is crucial to know the factors that influence corrosion. From that, the material performance can be improved, and effective corrosion prevention strategies will be developed.

The water chemistry is one of the most important factors that affect corrosion behaviour. The composition of water, including dissolved oxygen content, mineral concentration, conductivity, pH and salinity, can have a significant impact on the electrochemical reactions occurring at the surface of the metal (Jones, 2013). As a rule, water with higher concentrations of dissolved ions has higher electrical conductivity, which promotes corrosion. Therefore, the corrosion of metals may be of different degrees for different types of water.

Among the common water sources, seawater is considered to be highly corrosive because of the high concentration of dissolved salts especially chloride ions. Chloride ions can enter and remove protective oxide films from metal surfaces and accelerate corrosion reactions (Melchers & Jeffrey, 2008). Reverse Osmosis (RO) water, however, has much lower levels of dissolved minerals and salts, as contaminants are filtered out by membrane filtration. Hence, RO water is expected to be less aggressive in corrosion environment.

Mineral waters such as Spritzer and Desa contain varying levels of naturally occurring minerals, including calcium, magnesium, sodium, and bicarbonates. Dissolved minerals can affect the electrochemical characteristics of water; hence, the corrosion behaviour of metal may differ between RO water and seawater (Davis, 2000). Similarly, tap water contains dissolved minerals and treatment chemicals that may contribute to corrosion processes depending on water quality characteristics.

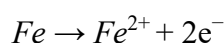
Although numerous studies have investigated metal corrosion in marine and industrial environments, limited information is available regarding the comparative corrosion behaviour of metal exposed to different water sources commonly encountered in everyday applications. Therefore, evaluating the corrosion performance of mild steel in various water environments can provide valuable information for material selection, maintenance planning, and corrosion management.

There are five types of water sources used in the immersion test of mild steel rod specimens in this study, namely tap water, Reverse Osmosis (RO) water, Spritzer mineral water, Desa mineral water, and seawater. Corrosion behaviour of the mild steel rod was studied for a seven-week immersion period using mass loss, changes in diameter and length, corrosion rate, and Biochemical Oxygen Demand (BOD). The ASTM G31 mass-loss method was used to quantify the corrosion rate, and statistical comparisons were made to assess the effect of water type on corrosion performance. The findings of this study are expected to contribute to a better understanding of the relationship between water quality and metal corrosion behaviour. Furthermore, the results may assist engineers, researchers, and industries in selecting appropriate materials and implementing effective corrosion control measures for systems exposed to various water environments.

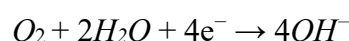
Literature Review

Corrosion of Metal

Corrosion is the degradation of a material as a consequence of its interaction with the environment (Fontana, 2005). Corrosion of metal occurs due to electrochemical oxidation reactions in which metal atoms lose their electrons and become metal ions. These ions then react with oxygen and water to form hydrated metal oxides sometimes called rust (Jones, 2013). The corrosion process includes anodic and cathodic reactions.



while the cathodic reaction in neutral or alkaline water commonly involves oxygen reduction:



The formation of corrosion products may either accelerate or reduce further corrosion depending on their protective properties (Revie & Uhlig, 2011).

Factors Affecting Corrosion

The behavior of metals in water is mostly due to the chemical composition of water. The pH, dissolved oxygen, conductivity, salinity and mineral content influence the electrochemical processes driving metal degradation (Davis, 2000). As Jones (2013) points out, the higher the ionic concentrations the better the conductor, the easier the flow of electrons, the faster the corrosion. Purified water, in contrast, has so little dissolved ions that it is usually much less aggressive to metals.

In corrosion oxygen also plays an important role as the electron acceptor in cathodic reduction. The speed of corrosion and oxygen reduction is directly dependent on the amount of oxygen was dissolved (Schweitzer, 2010). Fontana (2005) also observed that oxygen availability frequently sets the pace of corrosion in aqueous systems, particularly where ferrous metals are exposed to neutral conditions.

Salinity matters most of all in marine environments. As loaded with chloride ions, seawater is particularly harsh on metallic materials. These ions slip through the thin oxide layers that normally shield metal surfaces, opening the door to localized forms of attack such as pitting

corrosion (Melchers and Jeffrey, 2008). It is hardly surprising, then, that seawater is widely considered one of the most corrosive natural environments for iron and steel structures (Revie & Uhlig, 2011).

Corrosion in Different Water Sources

Seawater contains a large number of dissolved salts like sodium chloride. Most importantly they increase conductivity and increase corrosive activity. According to Melchers and Jeffrey (2008) chloride-induced corrosion is one of the main causes of deterioration in marine structures and offshore facilities. The salinity is high enough to speed up electrochemical reactions and to cause corrosion rates to be considerably higher than in fresh water.

Reverse osmosis (RO) is a process where water is pushed through a membrane that eliminates dissolved ions, minerals, and contaminants, so the resulting RO water has far less conductivity than the untreated sources (Davis, 2000). Studies have shown that lower ionic concentrations dampen electrochemical activity, which may in turn bring corrosion rates down in metallic materials (Schweitzer, 2010). Subsequently, RO water should present a far gentler corrosion environment than seawater or tap water.

Unlike distilled water, mineral water contains naturally occurring minerals from the source, such as calcium, magnesium, sodium and bicarbonates. The quantity of each mineral in the bottle differs from brand to brand, depending on the source of the water and the treatment it undergoes. Davis (2000) has stated that dissolved minerals can increase water conductivity and steer the corrosion behaviour in different directions depending on their concentration and chemical makeup. Commercial brands such as Spritzer and Desa may therefore behave quite differently from both RO water and seawater when it comes to corrosion.

In between RO water and seawater, tap water contains dissolved minerals along with the treatment chemicals added during water treatment. According to Jones (2013) the corrosive behaviour depends largely on local water quality, such as hardness, pH, chloride concentration, and dissolved oxygen levels. As a result, corrosion of metal pipes is still a chronic concern in many distribution systems, as extended contact to tap water can gradually erode metallic infrastructure (Schweitzer, 2010).

Measurement of Corrosion Rate

Mass loss method is used to evaluate the corrosion rate due to the reliability. Measuring corrosion rate by using weight loss calculation is standardized in ASTM G31. The standard requirement for laboratory immersion testing to use weight loss because it provides a direct, quantitative measure of how much material has actually been lost (ASTM International, 2021). The corrosion rate can be calculated using:

$$CR = \frac{8.76 \times 10^4 W}{AT_\rho}$$

where:

CR = Corrosion rate (mm/year)

W = Weight loss (g)

A = Exposed surface area (cm²)

T = Exposure time (h)
 ρ = Density of metal (g/cm³)

Biochemical Oxygen Demand (BOD) and Water Quality

BOD or Biochemical Oxygen Demand is a measure of the organic pollution and water quality. BOD is a measure of the oxygen used by micro-organisms in degrading organic matter in water (Sawyer et al., 2003). Changes in BOD values can be a result of water chemistry and indirectly affect corrosion behaviour by changes in dissolved oxygen concentrations. Thus, monitoring of BOD during corrosion experiments can provide additional insight into changes occurring in the immersion media.

Research Gap

The significant study about environment circumstances towards corrosion behaviour on metal have demonstrated by previous studies. Melchers and Jeffrey (2008) discovered that chloride attack mechanisms in marine environments lead to greater corrosion rates. Similarly, Revie and Uhlig (2011) founded that corrosion rates rise with increasing salinity and conductivity. Meanwhile, Davis (2000) discovered that water with a lower concentration of dissolved ions had less corrosion activity due to its reduced electrical conductivity. This finding supports the use of RO water as a less aggressive corrosion environment. According to Jones (2013), corrosion behaviour is determined by the combination of pH, dissolved oxygen, salinity, and mineral concentration.

Methodology

This study used an experimental immersion method to study the significant of various water sources on mild steel rod corrosion behaviour. Five types of water were used as testing media: tap water, Reverse Osmosis (RO) water, Spritzer mineral water, Desa mineral water, and seawater. 3 metal rod of similar dimensions were prepared for each water samples. Their initial mass, length, and diameter were measured using a digital balance and vernier calliper before the immersion. The specimens were then immersed in 25 mL of the respective water sample contained in a 50 mL beaker and exposed under laboratory conditions for a period of seven weeks. During the experiment, measurements of mass, length, and diameter were recorded weekly to monitor changes in the physical characteristics of the mild steel rods. The details of the mild steel rod sample are shown in Table 1:

Table 1: Dimension Of Metal Rod Sample

Type of Metal	Length	Diameter	Density, ρ
Mild Steel	~50 mm	~20 mm	7.85 g/cm ³

Biochemical Oxygen Demand (BOD) tests were conducted at at day one and last to evaluate changes in water quality during the immersion period. Corrosion performance was assessed using the mass-loss method in accordance with ASTM G31 standards, where the difference between the initial and final mass of each specimen was used to determine weight loss. The corrosion rate was subsequently calculated using the standard corrosion rate equation by considering the specimen surface area, exposure time, and density of iron. The collected data, including mass loss, corrosion rate, diameter change, length change, and BOD values, were

analysed to determine whether different water sources significantly influenced the corrosion behaviour of iron rods.

Result and Discussion

Mass Loss Analysis

Table 2: Mass Reduction For Most Specimens Throughout The Seven-Week Immersion Period.

Water Source	Initial Mass (g)	Final Mass (g)	Mass Change (g)
Tap Water	123.83	123.34	-0.49
RO Water	123.57	123.60	+0.03
Spritzer	123.85	123.61	-0.24
Desa Water	123.72	123.49	-0.23
Seawater	124.16	123.94	-0.22

Observation from the mass loss results, the corrosion behaviour of mild steel rods was varied depending on the water source used during the immersion period. Mass loss is widely recognized as one of the most reliable indicators of corrosion because it directly quantifies the amount of material removed from the metal surface (ASTM International, 2021; Fontana, 2005). Before weight the immersed sample, all the samples were scooped out from the water and allowed to air dry after being gently cleaned.

As shown in Table 2, tap water produced the greatest overall mass reduction, while RO water exhibited additional mass, indicating a solid corrosion layer occurred on its surface. Comparable observations have been reported by Davis (2000) and Schweitzer (2010), who noted that water containing higher concentrations of dissolved ions generally promotes electrochemical reactions and increases corrosion rates.

The bigger loss of mass seen in tap water could be because of the minerals that are dissolved in it the chemicals used to treat it. The oxygen that is in it. These things make the water better at carrying electricity. Help the process of rusting (Jones, 2013; Revie & Uhlig 2011). As Ahmad said in 2006 the ions that are dissolved in water make the water better at carrying electricity and speed up the rusting of metal. Morcillo and others found in 2014 that even a little bit of salt in the water can have an effect on how metal rusts in the air or in water.

Even though seawater is usually considered hard on iron and steel the results here showed that it caused less mass loss than tap water. This could be because of the layers of rust that form. Slow down the rusting process (Melchers & Jeffrey 2008; Neville, 2002). Melchers also found something in 2003. He saw that over time the rust that forms in the sea can protect the metal and change how fast it rusts.

The smallest loss of mass happened in RO water. This matches with studies that said that clean water is better at stopping rust because it has very few minerals and ions (Davis, 2000; Schweitzer, 2010; Roberge, 2008). So, the results about mass loss show that the type of water affects how iron breaks down. Reducing the number of ions in the water can make a difference, in stopping rust.

Diameter Change Analysis

From the measurement of diameter during experiment, the diameter of mild steel rod happen to change and reflected the rate of corrosion. Measurements revealed changes in specimen diameter, signifying the rate of corrosion and surface changes. Such dimensional changes are commonly associated with the formation and detachment of corrosion layers on the metal surface (Revie & Uhlig, 2011).

The result indicate seawater caused the most significant change in diameter. Similarly, studied by Melchers & Jeffrey (2008) and Neville (2002), they found that high-chloride environments exhibit higher corrosion rates and compromise the stability of protective oxide layers. Chloride ions can penetrate the corrosion product layer, creating localized anodic regions that accelerate metal degradation (Uhlig, 2008; Ahmad, 2006).

However, the presence of dissolved minerals and oxygen such as found in tap water will cause dimensional instability of the metal. Therefore, the availability of oxygen is often a controlling factor in aqueous corrosion systems. This is due to its involvement in the cathodic reduction reaction (Fontana, 2005). Jones (2013) also reported similar results. The changes in the dissolved oxygen concentration significantly affect the metal oxidation rate.

RO water has stable size. This is consistent with findings of previous researchers who have reported that low conductivity environments reduce electrochemical activity and reduce metal deterioration (Davis, 2000; Roberge, 2008). The intermediate behaviour observed for the mineral water samples may be explained by the presence of dissolved calcium, magnesium and sodium ions that increase the conductivity in relation to the purified water (Sawyer et al., 2003). Overall, the results from diameter changes have confirm that environments containing greater concentrations of dissolved salts and minerals produce more extensive surface degradation than purified water environments, in agreement with previous investigations (Morcillo et al., 2014; Revie & Uhlig, 2011).

Corrosion Rate Analysis

Weight loss analysis in accordance with the ASTM G31 standard shows that the corrosion activity is maximum at the beginning of the immersion period and decreases gradually with the exposure time. This is consistent with the normal corrosion behaviour of mild steel which is normally aggressively oxidized at the beginning and then inhibited by the formation of corrosion products (ASTM International, 2021; Fontana, 2005). Figure 1 shows that the corrosion rate subsequently decreases due to the formation of an oxide layer on the surface which partially obstructs the attack of the corrosive species. Revie and Uhlig (2011) explain that the formation of such a film limits direct interaction between the base metal and the environment which is supported by findings of inherent protective quality. This mechanism is further detailed by Melchers (2003) and Roberge (2008), noting that the aging of the corrosion layer disrupts reaction kinetics by restricting ion transport and oxygen diffusion.

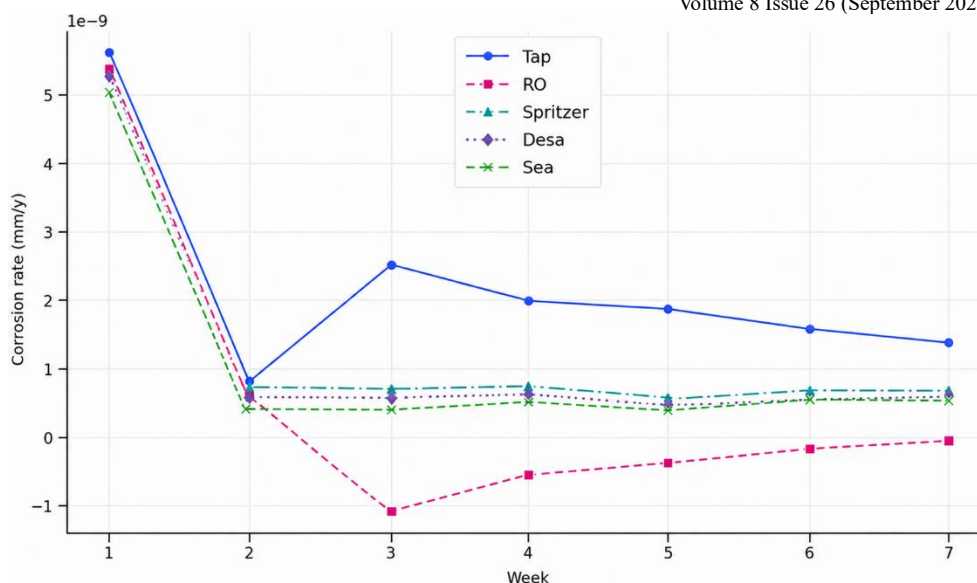


Figure 1: Corrosion Rates (weekly) of Mild Steel Rods in Different Water Media

The low corrosion-rate values observed in RO water support previous findings that purified water environments significantly reduce electrochemical activity because of limited ionic conductivity (Schweitzer, 2010; Davis, 2000). Conversely, seawater maintained measurable corrosion activity throughout the experiment due to its chloride content. According to Neville (2002), chloride ions interfere with the stability of passive films and promote pitting and localized corrosion processes. Similar observations were reported by Melchers and Jeffrey (2008), who identified salinity as a major factor controlling marine corrosion.

The mineral waters gave intermediate corrosion rates over the whole period of the experiment. This behaviour is consistent with research showing that dissolved minerals increase conductivity and enhance electrochemical reactions, but not to the extent seen in highly saline environments (Jones, 2013; Ahmad, 2006).

Overall, the corrosion-rate analysis demonstrates that water chemistry remains a dominant factor influencing iron deterioration, supporting the findings reported by Revie and Uhlig (2011), Schweitzer (2010), and Morcillo et al. (2014).

Biochemical Oxygen Demand (BOD) Analysis

The BOD studied by Sawyer et al., (2003) revealed that the water quality in tap water and saltwater changed over time as the materials were present. BOD is commonly used to determine how much biological and chemical activity is occurring since it indicates how much oxygen is required to break down substances. Table 3 shows that BOD levels increased in both tap water and ocean. This suggests that the surroundings need oxygen when the items were in the water. Metcalf and Eddy (2014) noted that high BOD levels can indicate biological activity, chemical processes, or pollutants in the water. The amount of oxygen in the water is important because it affects how corrosion happens. Oxygen is necessary for some types of corrosion to occur (Fontana, 2005; Revie & Uhlig, 2011). Jones (2013) found that the amount of oxygen in the water can control how fast corrosion happens in water that's not too acidic or too basic. There is also a connection between the amount of oxygen in the water and how iron corrodes (Schweitzer, 2010).

The BOD in the RO water was stable which indicated that the purified water remained chemically stable during the experiment. This makes sense because we did not observe the corrosion in the specimens exposed to the RO water. Similarly Davis (2000) and Sawyer et al. (2003) have found that mineralised water seems to have a lower level of electrochemical and biological activities possibly due to certain chemical buffering and osmotic effect.

Even though BOD does not directly show how much corrosion is happening the results suggest that changes in water quality can affect how corrosion happens by changing the amount of oxygen in the water and the environment, around the metal. Other people have found things when they studied how water chemistry affects how metals corrode. BOD analysis and corrosion are related because BOD shows how much oxygen is needed to break down things and oxygen is necessary for some types of corrosion to occur (Metcalf & Eddy, 2014; Schweitzer, 2010).

Table 3: BOD Measurement for Different Water Samples in Mg/L.

Water Source	Week 0	Week 7
Tap Water	92.87	98.08
RO Water	97.93	97.30
Spritzer	95.93	96.80
Desa Water	96.97	96.95
Seawater	91.00	96.80

Conclusion

In this study, the corrosion behaviour of iron rods immersed in five different water sources namely tap water, Reverse Osmosis (RO) water, Spritzer mineral water, Desa mineral water and seawater was successfully investigated over a period of seven weeks of immersion. Mass loss, diameter change, corrosion rate and Biochemical Oxygen Demand (BOD) measurement were used to evaluate the corrosion performance of the specimens.

The experimental results showed that the water chemistry has a significant influence on the corrosion behaviour of iron. The differences in corrosion response of the tested media were attributed to differences in the dissolved minerals, salts and other water constituents. The mass loss analysis indicated that tap water had the highest total reduction of the specimen mass. RO water had the lowest mass loss indicating better corrosion resistance. The mineral water samples (Spritzer and Desa) produced intermediate corrosion effects, whereas seawater showed persistent corrosion activity associated with its high salinity and chloride ion concentration.

The diameter change analysis further confirmed the influence of water composition on corrosion behaviour. Seawater exhibited the largest dimensional fluctuations throughout the experiment, reflecting continuous formation and removal of corrosion products on the specimen surface. In contrast, RO water maintained the most stable dimensions, suggesting that reduced ionic content limited electrochemical reactions responsible for metal degradation.

Corrosion rate calculations revealed that all specimens had the highest corrosion activity during the first stage of immersion. The following decrease in corrosion rates suggests the creation of corrosion-product layers, which partially hindered further metal breakdown. Despite this reduction over time, specimens exposed to water sources with higher concentrations of dissolved salts and minerals exhibited stronger corrosion activity than those immersed in purified water.

The BOD measurement presented high variations in water quality during the experiment, especially in the tap water and ocean. The increase is indicative of change of chemical and biological environment during immersion which may have caused differences in corrosion performance. BOD is not a direct corrosion parameter, but the changes observed in BOD suggest interactions of the iron specimens with the surrounding media during the period of exposure.

In general, the results support the strong dependence of metal corrosion resistance on water quality characteristics. RO water was the most favourable media for iron integrity among those tested, whereas seawater and tap water presented a greater risk of corrosion-related degradation. Thus, the study emphasises the necessity of taking into account the water composition when selecting materials for engineering, domestic and marine applications with long-term contact with water.

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Author Contribution Statement: All authors contributed significantly to the development of this manuscript. First author was responsible for the conceptualization, methodology, and overall supervision of the study, handled data collection, analysis, and interpretation of results. Second author contributed to the literature review, drafting, and critical revision of the manuscript. All authors read and approved the final version of the manuscript prior to submission.

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