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Comparative Analysis of Mild and Carbon Steel Corrosion in Palm Oil Mill Effluent

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Abstract— *The purpose of this study is to investigate and compare the corrosion behavior of mild steel and carbon steel in Palm Oil Mill Effluent (POME) environment with fresh water as the control experiment. In the course of this study, some physicochemical properties of the Palm oil mill effluent and the fresh water such as temperature, pH, electrical conductivity, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Dissolved Oxygen (DO) were determined to ascertain their susceptibility to corrosion. These parameters were monitored throughout the period of the experiment alongside the corrosion rate of the steels, which lasted for a total of 2016 hours. The corrosion rates of both steels were determined using the conventional weight-loss method and the results compared in both environments. The results showed that both steel materials are slow to corrosion in POME, though, mild steel showed higher corrosion rates than carbon steel. The results of the physicochemical analysis revealed that electrical conductivity emerged as the pivotal contributor to corrosion dynamics. The average corrosion rates of mild steel and carbon steel were found to be 2.3474mpy and 1.2473mpy in POME and 7.3037mpy and 4.5538mpy in fresh water environments respectively. Similarly, the result shows that POME is a possible inhibitor to metal corrosion.*

Keywords— *Carbon steel: corrosion: mill effluent: mild steel: palm oil: physicochemical.*

I. Introduction

Fresh palm oil mill effluents (POME), is thick brownish colloidal slurry water containing oil, and fine cellulosic fruit debris. The open pounding system for palm oil effluent treatment was commonly preferred because of its cost effectiveness and low corrosion impact until recently when mechanical systems with advanced technology was introduced because of the stringent discharge conditions and also the high cost of land. This advanced mechanical and biological treatment of POME involves equipment and structures of steel which are prone to corrosion (Arezoo *et al.,* 2022; Muhammad *et al.,* 2019).

Corrosion occurs due to the physicochemical interaction of metals with their environment. It is also an electrochemical reaction between a material usually metal and its environment that results in the deterioration of the metal and its property. It is a process that reverses a refined metal to its original ore. It weakens the strength of metal and has the potential to impair the function of the metal, environment or the technical system of which the metal forms a part (Amadi *et al*., 2024; Amadi & Wami 2023).

Mild steel has outstanding ductility and toughness; weld ability, which makes its applications possible in the engineering fields. However, the corrosion resistance of mild steel is comparatively limited, and promotes many corrosion problems in related industry, (Amadi & Ukpaka 2016; Chuka *et al.,* 2014; Wan *et al.,* 2011).

Despite its relatively limited corrosion resistance, carbon steel is also widely used due to its excellent mechanical properties, ability to increase hardness, strength of steel and low cost (Izionworu *et al*., 2022; Amadi & Ukpaka 2015; Esparza *et al.,* 2011).

Factors contributing to corrosion from palm oil mill effluent are high temperatures, dissolved solids, dissolved oxygen, and pH. High Quantity of water has a major impact in metallic corrosion. Warm and moist environment in effluent treatment system is ideal for promoting biological growth, and will lead to increasing oxygen in the effluents which promotes corrosion, (Amadi & Wami 2009; Varadarajan, 1998). Pollution associated in the palm oil mills has high biological oxygen demand (BOD) imposed by the organic effluents, chemical oxygen demand (COD), low pH, high temperatures, excessive solids, oil and grease. These parameters, in isolation or together has a major impact on the metals used in the mills and in the effluent treatment system, (Mosunmola & Olatunde, 2020).

Very few major mills in Nigeria have effluent water treatment plant and major parts of the plants are heavily affected by corrosion (Igwe *et al.* 2007). Major area of environmental degradation from an oil palm mill is the air pollution resulting from boilers and incinerators, corrosion of chimneys, exhaust dusts, induced draft fan, multi-cyclone (Yi *et al*., 2019; Yue & Jeng 2019).

Different researchers have emphasized on the negative impact of indiscriminate disposal of palm oil mill effluent on agricultural farmlands including soil properties, microorganisms, plants and the entire ecosystem (Nwachukwu *et al.,* 2018).

The need to curtail the deleterious nature of palm oil mill effluent has been studied. Mosunmola *et al.,* 2020 and Nwachukwu *et al.,* 2018 in their respective studies suggested how the palm oil mill effluent pollution could be curtailed. They suggested that biodegradation is the most promising technology for treating POME polluted site because it is cost-effective and enhances complete mineralization.

POME has been identified as one of the major sources of water pollution. The release of untreated POME into rivers and lakes is a major source of concern (Phaik *et al*., 2020; Jumadi *et al.,* 2020). Three major sources by which POME are generated have been identified (Muhammad *et al.,* 2019; Carrere 2010).

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The composition of POME has been studied (Ma 2000; Noor *et al.,* 2021). It was further suggested that POME is a major source of greenhouse gases occasioned by biogas emission (Ardian *et al.,* 2022; Mustapha *et al.,* 2017).

The treatment of POME via anaerobic digestion has undoubtedly made it difficult to determine the level of pollution caused to water bodies by POME when discharged into the water (Wu *et al*., 2009). Investigation has revealed that uniform corrosion occurred when mild steel was exposed to mill paper effluent (Ram *et al.,* 2012). In addition, it has been stated that pitting is favoured by acidic pH level, high chloride, higher temperature of liquor, and media having oxidizing chemicals. These conditions accelerate steel corrosion (Amadi & Wami 2011).

The effect of POME on engineering materials as reviewed in literature cannot be over emphasized. It is known that most of the materials used for the construction of Palm Oil Mills are mild and carbon steel. The comparison of the corrosion rate between these two steel types in Palm Oil facilities is lacking in literature. The need to bridge the knowledge gap in existing literature gave birth to this study.

It is the purpose of this paper to produce primary corrosion data for mild and carbon steel in POME and fresh water environments and comparing the rate of corrosion of these steel types which could be needful for Environmental Impact Assessments (EIA) before, during and after construction of palm Oil processing Mills in Niger Delta region of Nigeria.

II. MATERIALS AND METHODS

2.1 Materials

The materials used include pH meter with glass electrodes, Electrical conductivity meter, Thermometer, Weighing balance, Venier caliper, Analytical balance, Oven, Desiccators, Supporting iron rods, Emery paper, Plastic bag, Conical flask, Pipette, Burette, Ruler, Iron , Sponge, beaker, Acetone, Erichrome black T indicator, Standard buffer solution, Ammonia buffer solution, 0.02m EDTA solution, Potassium chloride solution, Hydrochloric acid, Distilled water, Detergent, Mild steel, Carbon steel, polypropylene ropes

2.2 Methods

2.2.1 Sample Collection

2.2.1.1 Fresh Water Collection

Fresh Water sample was collected from a bore-hole situated in the same environment in Niger Delta where the Palm oil mill that generates effluent is situated. Water sample was collected as outlined in (Amadi & Wami, 2009). Fresh water is filled to the 25 Litre calibrated mark on the plastic container.

2.2.1.2 Palm Oil Mill Effluent (POME) Collection

Palm oil mill effluent (POME) sample was collected from a palm oil mill situated in Apani community in Ikwerre Local Government Area of Rivers State. POME was collected as outlined in (Amadi & Wami, 2009). POME was filled to the 25 Litre calibrated mark on the plastic container.

All samples were taken to the laboratory for analysis.

2.2.2 Preparation of Corrosion Coupons

The mild and carbon steel Coupons used for the study was obtained from the mechanical workshop of the department of mechanical engineering, Rivers State University, Port-Harcourt. A total of 24 corrosion coupons were prepared and used for the study. The method used in preparing the corrosion coupons is consistent with the literature (Amadi *et al.,* 2010; Amadi & Wami, 2023).

2.2.4 Experimental Procedure for the Corrosion Experiment

The experimental procedure is consistent with the literature (Amadi, 2015; Amadi & Wami, 2009). A total of Twenty Four (24) corrosion coupons were prepared and used for the study. Six (6) pieces of mild and carbon steel coupons each were immersed and suspended in the water and POME with the help of a polypropylene rope.

The coupons were retrieved at intervals of 336 hours (14 days) from both water and POME samples and the coupons washed with distilled water, cleaned, dried and reweighed. The process was repeated every 336 hours (14 days) for a total period of 2016 hours (84days). The physicochemical properties of the water and POME samples were tested each day of retrieving the coupons. The parameters tested for include temperature, pH, electrical conductivity, dissolved oxygen, chemical oxygen demand (COD) and biological oxygen demands (BOD).

III. RESULTS AND DISCUSSION

3.1 pH

Fig. 1 below shows the pH of Palm Oil Mill Effluent (POME) and fresh water environments with respect to time. The pH level, recognized as a significant factor influencing corrosion rates (Noor *et al.,* 2021; Amadi & Wami 2009), was observed to be higher in the fresh water compared to the palm oil mill effluent (POME) as shown in Figure 1 below.

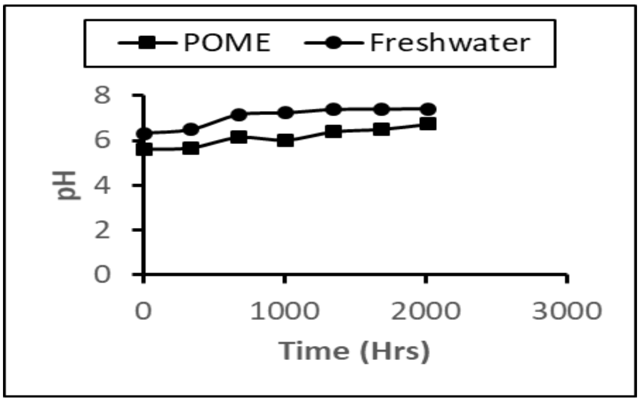

Fig. 1: pH of POME and Fresh Water against Time.

The pH of palm oil mill effluent exhibited a slightly acidic nature initially but consistently increased over time. The increase in pH may be due to depletion of nutrients in POME by the activities of microorganisms (Amadi & Wami, 2023). The result also proves that POME is a possible inhibitor to metal corrosion. In contrast, the pH of fresh water remained approximately neutral throughout the experiment. The increase in the pH values of fresh water with respect to time

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may be as a result of loss of ions due to evaporation into the atmosphere (Amadi *et al*., 2024).

3.2 Temperature

Fig. 2 below, illustrates the temporal variation of temperature in POME and fresh water. Temperature is also an important factor influencing metal corrosion. A rise in temperature of an environment will cause increase in corrosion rate of the metal exposed to it (Izionworu *et al*., 2021). Though, the effect of temperature in both POME and fresh water environments is negligible since the temperature values are within the ambient temperature of the natural environment.

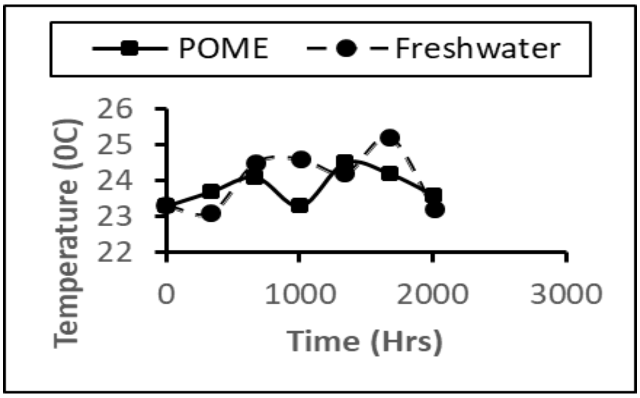

Fig. 2: Temperature of POME and Fresh Water against Time

3.3 Electrical Conductivity

The electrical conductivity of mild and carbon steel measured during the experiment is shown in Fig. 3 below. The electrical conductivity of a fluid is an important factor that significantly influences the rate of corrosion (Amadi & Wami, 2009). Increase in electrical conductivity of an environment can significantly result to an increase in the corrosion rate of metal exposed to it (Amadi, 2015).

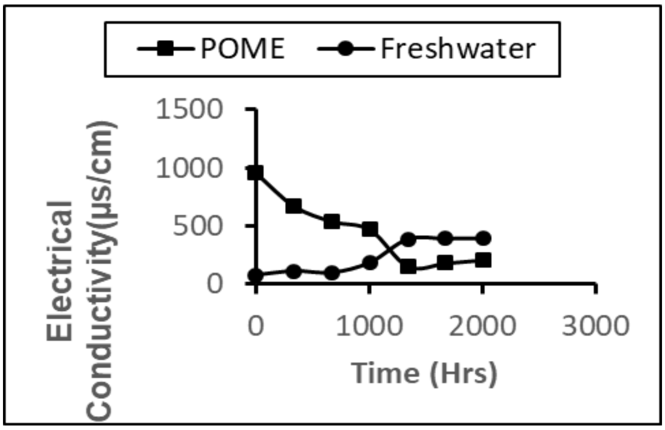

Fig. 3: Electrical Conductivity of POME and Fresh Water against Time

In Figure 3 below, it is evident that the electrical conductivity of the fresh water, increased steadily from the beginning of the experiment. The increase of electrical conductivity in fresh water environment can be because of the rapid transfer of metallic ions from the steels to the water environment, making the water more metallic. In contrast, the electrical conductivity of POME steadily decreased over time and can be because of the oil content of POME, lubricating the steel materials and reducing the interactions with the metallic ions. The spontaneous decrease in electrical conductivity of POME with time also indicates a concurrent reduction in corrosion rates.

3.4 Dissolved Oxygen (DO)

In Fig. 4, the variation of dissolved oxygen (DO) levels in POME and fresh water is illustrated. The decrease in dissolved oxygen values in POME could be attributable to the utilization of oxygen as substrate by microorganisms (Mohamad *et al.,* 2020; Xu *et al.,* 2017). The oily nature of POME is yet another factor that could lead to low DO since it is known that penetration of oxygen into POME may be restricted compared to that of fresh water (Arezoo *et al.,* 2022).

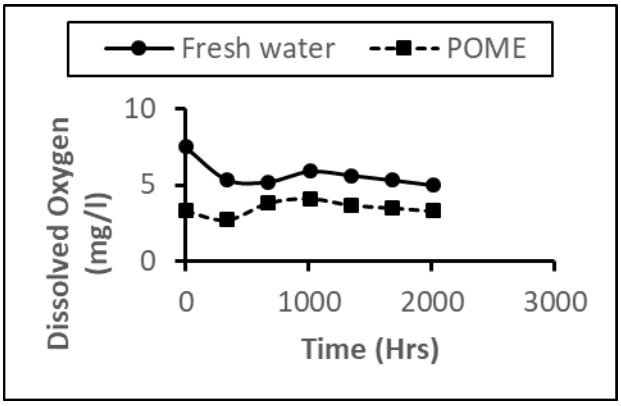

Fig. 4: Dissolved Oxygen (DO) of POME and Fresh Water

3.5 Biological Oxygen Demand (BOD)

Fig. 5 below shows that the BOD in POME exceeds that of fresh water. This may be as a result of the high content of organic matter and elevated microbial activities in palm oil mill effluent compared to that of fresh water. Over time, as the organic matter is broken down and consumed by the microorganisms, the BOD reduces (Yoke *et al.,* 2021).

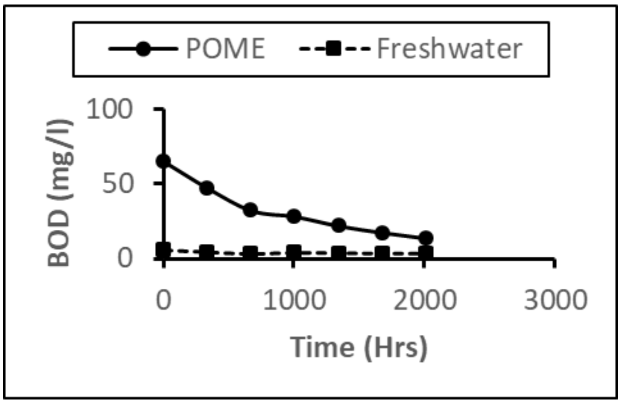

Fig. 5: BOD of POME and Fresh Water against Time

3.6 Chemical Oxygen Demand (COD)

In Fig. 6, it is evident that the COD of POME surpasses that of fresh water (control). This suggests a lower oxygen requirement for the oxidation of metals in POME, potentially leading to reduced or declining corrosion rates.

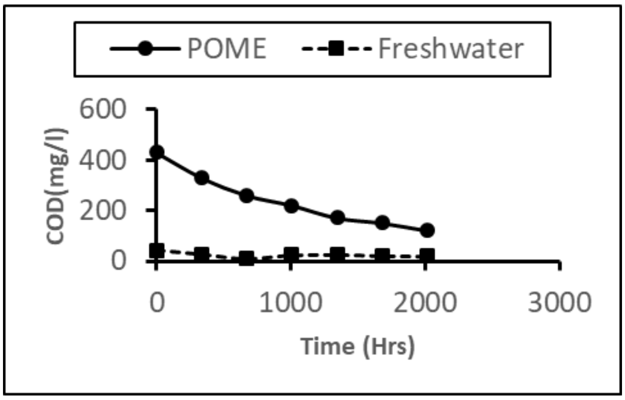

Fig. 6: COD of POME and Fresh Water against Time.

3.7 Corrosion Rate Analysis

Fig. 7 below shows the variation of weight loss of mild steel in POME and fresh water. In Fig. 7 and 8, it is evident that weight loss progressively increases over time, aligning with a proportionate rise in corrosion rate. Notably, the weight loss is consistently higher in fresh water when compared to POME. The data indicates a tendency for mild steel to undergo more substantial weight loss in fresh water relative to POME throughout the specified time intervals. The Figures offer valuable insights into the weight loss patterns of mild steel in both POME and fresh water across various time intervals, highlighting a prevalent trend of increased weight loss in the fresh water environment. This trend provides valuable insights into the dynamics of corrosion, highlighting potential periods of acceleration or deceleration over time.

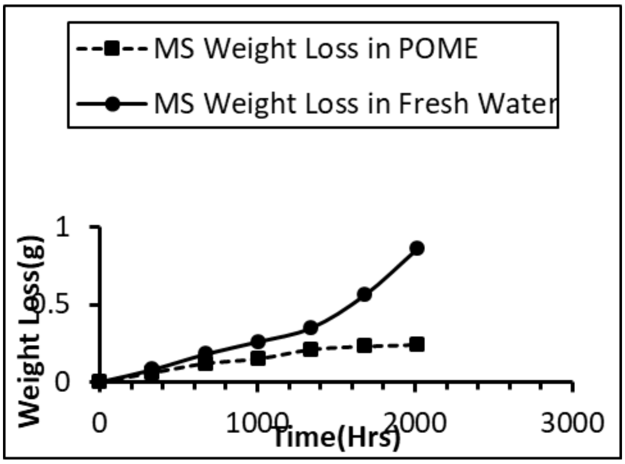

Fig. 7: Weight Loss of Mild Steel in POME and Fresh Water

In Fig. 9, mild steel in fresh water consistently displays higher corrosion rates compared to POME. The corrosion rate of mild steel in fresh water exhibits a notable upward trend over time, particularly after 1008 hours, indicating an increasingly corrosive environment. In contrast, the corrosion rate of mild steel in POME remains relatively stable and lower, suggesting a less aggressive corrosion environment and giving an indication that POME acts as an inhibitor as other plants extracts that have been reported (Izionwuru *et al.*, 2022; Ukpaka & Ekperi 2020).

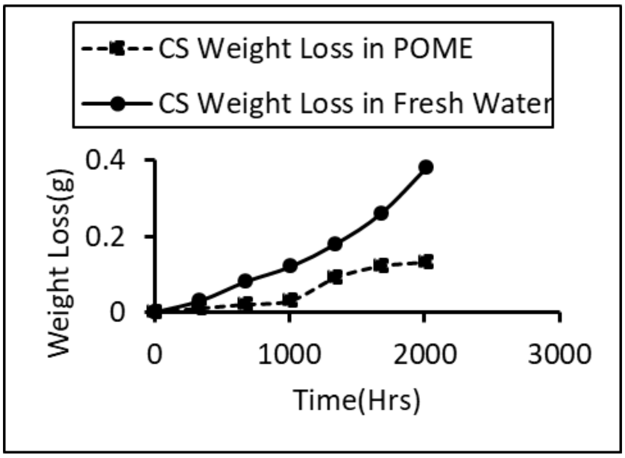

Fig. 8: Weight Loss of Carbon Steel in POME and Fresh Water

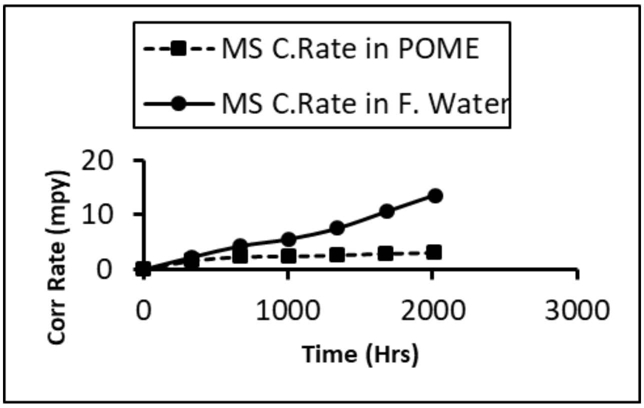

Fig. 9: Corrosion Rate of Mild Steel in POME and Fresh Water.

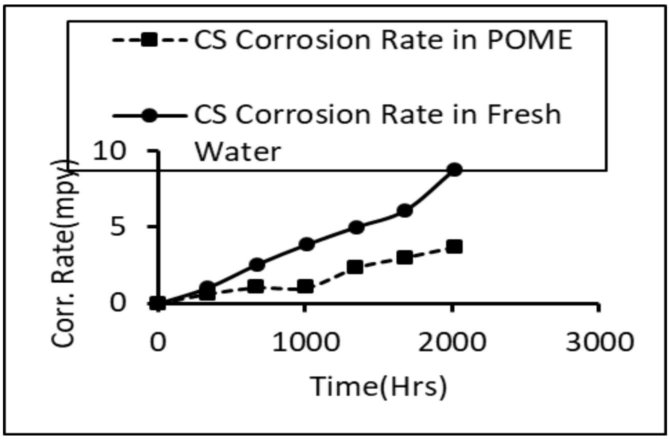

Fig. 10: Corrosion Rate of Carbon Steel in POME and Fresh Water

In Fig. 10, an examination of the corrosion rates of carbon steel in fresh water reveals a consistent upward trajectory over time. Conversely, in POME, the corrosion rate remains relatively stable but maintained an upward trend after 1008th hour. Fresh water consistently demonstrates higher corrosion rates for carbon steel in comparison to POME, particularly during later time intervals. This observation implies that the fresh water environment exhibits a more aggressive corrosive

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nature compared to POME over the specified time intervals. This result is also in agreement with the corrosion behavior of fresh water carried out by (Ukpaka & Ekperi 2020; Amadi *et al*., 2024).

Fig. 11 and 12 present a comprehensive overview of the weight loss and corrosion rates exhibited by Mild Steel and Carbon Steel over time in a fresh water environment. Both Mild Steel and Carbon Steel demonstrated a discernible upward trajectory in weight loss and corrosion rates as time progresses. The corrosion rates for both materials exhibited temporal fluctuations, suggesting dynamic responses to environmental conditions. Notably, carbon steel consistently maintains lower corrosion rates compared to mild steel, implying a potentially higher resistance to corrosion.

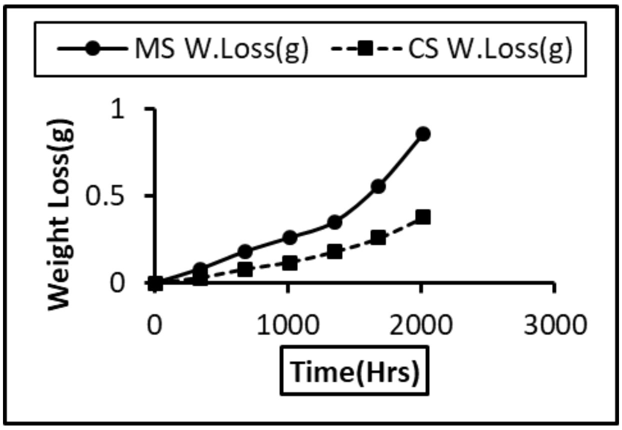

Fig. 11: Weight Loss of Mild and Carbon Steel in Fresh Water.

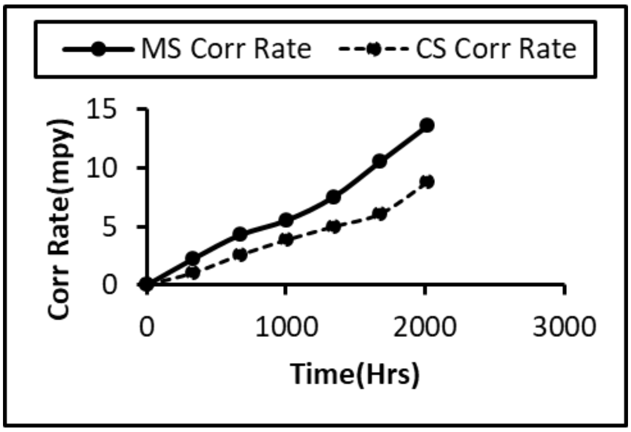

Fig. 12: Corrosion Rate of Mild and Carbon Steel in Fresh Water.

Fig. 13 and 14 showed the corrosion rates of mild steel and carbon steel in POME with time. At the initiation of the experiment (0 hours), both steels showed negligible corrosion. As time progresses, the corrosion rate of mild steel and carbon steel in POME increased. While mild steel maintained increase in corrosion rate as time progresses, carbon steel maintained the same rate in corrosion up to 1008th hour. After 1008th hour, the corrosion rate of carbon steel in POME marginally increased and continued throughout the period of the experiment.

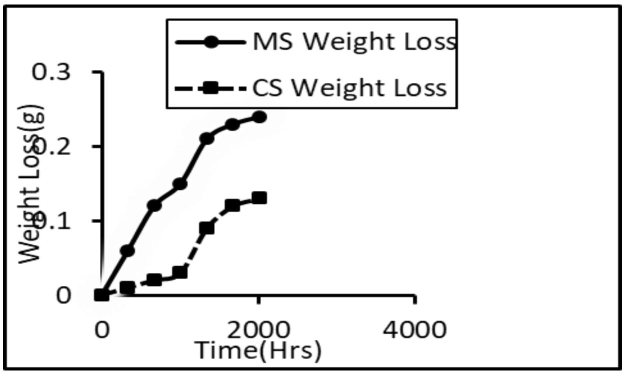

Fig. 13: Weight Loss of Mild and Carbon Steel in POME.

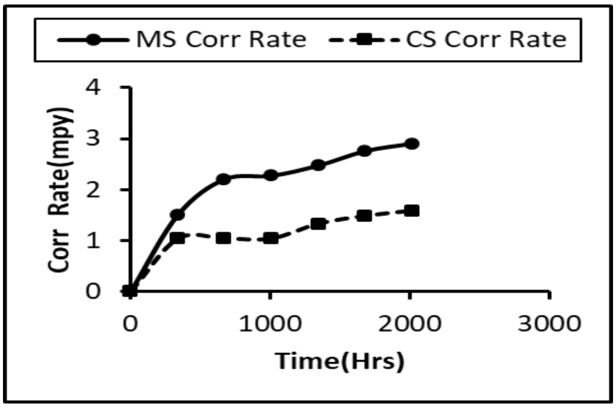

Fig. 14: Corrosion Rate of Carbon and Mild Steel in POME with Time.

IV. CONCLUSION

The analysis reveals upward trend in corrosion rates for both mild steel and carbon steel in fresh water and POME environments. The findings of this study further showed that corrosion occurred more in fresh water than in POME. This is attributable to the disparity in the values of the physicochemical properties of the two environments as investigated. However, the average corrosion rates of mild and carbon steel within the context of study were found to be 2.3474mpy and 1.2473mpy in POME and 7.3037mpy and 4.5538mpy in fresh water environments respectively. Similarly, this result shows that POME is a possible inhibitor to mild and carbon steel corrosion.

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