

## Effect of Oxygen Concentration on Corrosion Rate of Carbon Steel in Seawater

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**Abstract:** - Carbon steel is widely used in engineering applications and comprises about 85% of the annual steel production worldwide. With considering the cost of product, carbon steel has been widely employed as a construction material in oil and gas production. However, one of the major problems related to its use is its low corrosion resistance in this environment. An investigation has been carried out to evaluate the corrosion behaviour of AISI 1040 steel in artificial seawater and different sulphate ( $\text{SO}_4^{2-}$ ) to chloride ( $\text{Cl}^-$ ) ratio. The experimental was run under static conditions with controlled temperatures and the changes of weight loss, morphology and hardness was identified before and after corrosion attack. The materials experience extremely weight loss after corrosion attack and this indicate that uniform corrosion developed on AISI 1040. The Open Circuit Potential (OCP) shifted to more negative value in the non-oxygen solution which indicate that metals are susceptible to corrosion attack in high oxygen content. Morphology observation supports the corrosion product growth in oxygen content solution.

**Keywords:** - AISI 1040, Carbon Steel, Dissolved Oxygen and Corrosion Rate

### I. INTRODUCTION

Rusting is an important phenomenon accompanied with the corrosion of carbon steel and the formation of corrosion products such as iron oxides is an a biotic process of chemical reactions. It was generally agreed by most of the researches that carbon steels are generally attacked by uniform corrosion or general corrosion. The term 'uniform' or 'general' corrosion is used to describe the corrosion damage that proceeds in a relatively uniform manner over the entire surface of an alloy. It is an even rate of metal loss over the exposed surface. It also characterised by a chemical or electrochemical reaction or metal loss due to chemical attack or dissolution that proceeds uniformly over the entire exposed surface or over a large area. During this process, the material becomes thinner as it corrodes until its thickness is reduced to the point at which failure occurs. Corrosion attack of metal in seawater is dependent mainly on the salt content (which increase the electrical conductivity) and its oxygen content. A number of variables can influence and complicate the course of corrosion in different ways such as chloride, sulphate and temperature.

### Experimental Procedures

Linear polarisation tests were carried out in static conditions. Specimens with an electrical connecting wire were embedded in a non-conducting resin and the exposed surface with known area was subsequently ground using SiC sandpaper and diamond polished to a 6-micron finish. The sample was held in each solution for 5min before starting the experiment to stabilize the surface. This method makes use of a three-electrode electrochemical cell consist of reference electrode silver/saturated-silver-chloride (Ag/AgCl) half cell, the potential of which, versus normal hydrogen electrode (NHE), is +0.197 V. The working electrode is the sample and platinum is used as the counter electrode. This accelerated test method facilitates analysis of the kinetics of the corrosion reactions by controlling the potential between the reference and the working electrode and maintaining the current in the external cell between the counter and the working electrode. The potential is controlled by a computer-controlled potentiostat and is shifted at a constant rate in the anodic direction from the open circuit potential (OCP), causing the working electrode to become the anode and causing electrons to be

withdrawn from it. For linear polarisation, the measurement begins at approximately -20mV and scan in the positive direction to +20mV from OCP. The data are obtained from a linear plot of the potential versus current density graph. The slope of the graph was then calculated to obtain the corrosion rate by using the Stern and Geary equation.

**Results and Discussion**

The Tafel constants,  $\beta_a$  and  $\beta_c$  generally used were 120 mV/decade. It is strongly agreed by Hinds (2006) that any values between 60 and 120 mV/decade, a maximum error of only 20% can be expected [1]. To be sure, this value was identified by the Tafel polarization run for AISI 1040. In anodic polarisation tests, the electrode potential of the material is scanned from the free corrosion potential ( $E_{corr}$ ), also known as the Open Circuit Potential (OCP), in the more positive direction at a fixed rate. The preliminary test begins with identified the hardness of carbon steel before corrosion attack. However, the overall objectives of experiment was conducted is to quantify the effect of oxygen and anions to corrosion attack on carbon steel. Figure 1 shows anodic and cathodic polarisation of carbon steel in 3.5% NaCl in with and without oxygen content whereas Figure 2 and 3 presents the electrochemistry behaviour of carbon steel in higher sulphate content compared to seawater but same salinity and higher chloride content respectively. The OCP shifted to more negative value in the solutions with oxygen content which indicates that material's resistance to corrosion attack reduced [2]. The corrosion resistance of carbon steel depends on the oxygen activities combines with metal's composition to form a strong, protective oxide film on metal surface [3]. Figure 4 summarised the corrosion rate for AISI 1040 in all solutions. It is clearly presents that the corrosion rate is higher in solution with oxygen compared to without oxygen content. However, the corrosion rate in without oxygen content has shown no significant effect in every solution. The corrosion rate increased drastically in HCl (high chloride content) compared to in 3.5% NaCl and in  $H_2SO_4$  (sulphate); all solutions has same salinity, pH and temperature. This indicates that chloride accelerate corrosion attack on carbon steel drastically compared to sulphate.

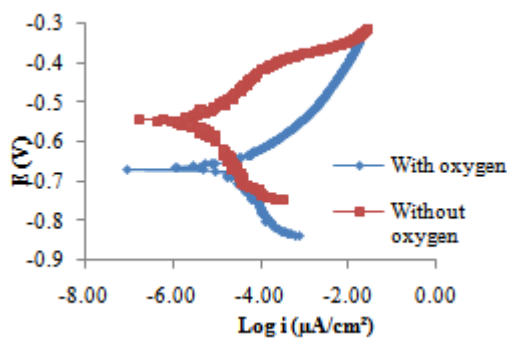


Figure 1: Carbon steel in 3.5%NaCl

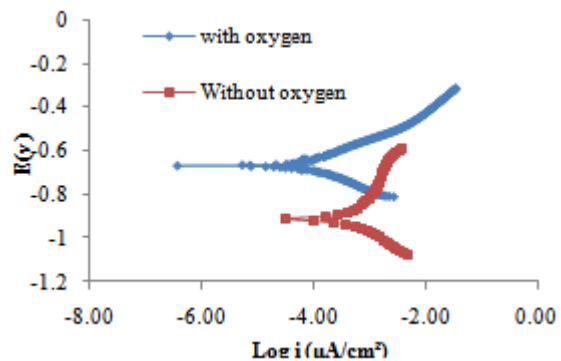


Figure 2: Carbon steel in sulphate content

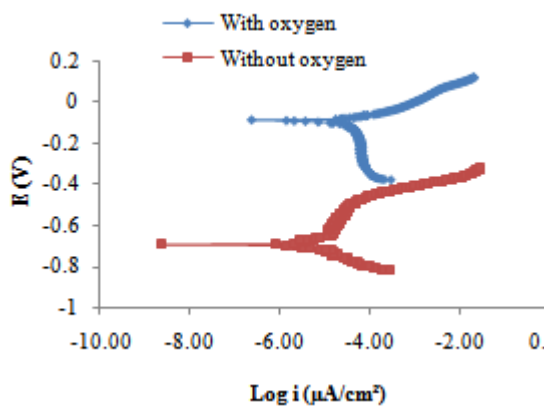


Figure 3: Carbon steel in 3.5%NaCl

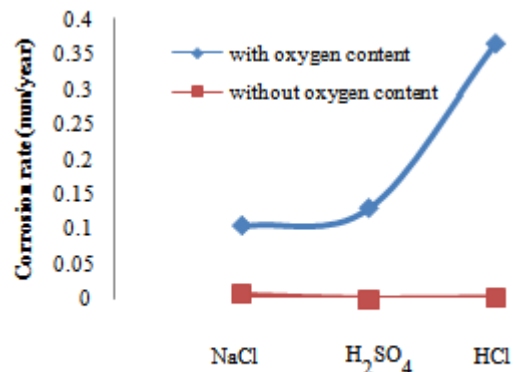


Figure 4: Carbon steel in sulphate content

The preliminary test begins with identified the hardness of carbon steel before and after corrosion attack. In all solutions, the hardness reduced after corrosion attack and carbon steel in high chloride content shows the highest reduction as shown in Figure 5. As the different hardness of the sample reduce, the resistance

of a material will increased which make the material less susceptible to corrosion. The weight loss also was determined before and after corrosion attack. The results are significant to hardness reduced in all solutions and chloride shown the highest weight loss compared to carbon steel in NaCl and H<sub>2</sub>SO<sub>4</sub> (Figure 6).

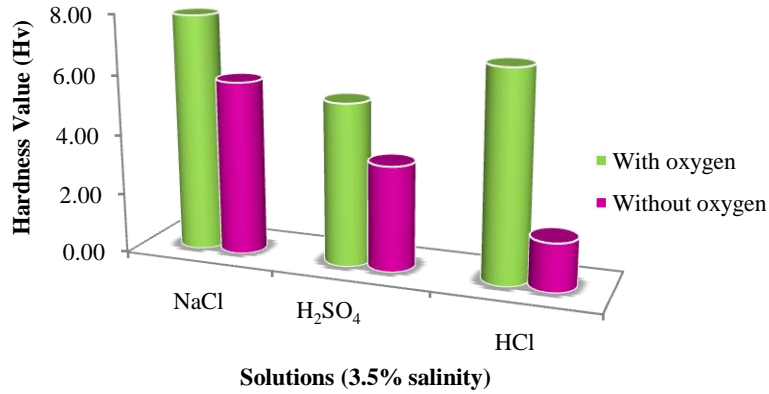


Figure 5: The hardness value for carbon steel in different solutions

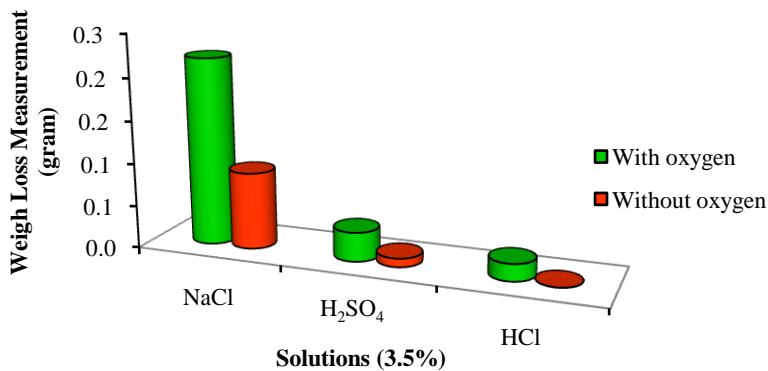


Figure 6: Weight loss of carbon steel in different solutions

The changes of the surface microstructure before and after the corrosion attack were observed by using optical microscope to show that the sample surface damaged due to corrosion attack. From the observation (Table 1), it showed that carbon steel corrodes severely in solutions with oxygen content and it form of small holes all over the surfaces. The holes of the corrosion product was observed using SEM to get a clearer image of the hole.

**Table 1: Optical observation on corrosion attack**

Before corrosion attack				
Solutions	NaCl	H <sub>2</sub> SO <sub>4</sub>	HCl	
Oxygen				
No oxygen				

**II. CONCLUSIONS**

The conclusion has been made according to corrosion rate of carbon steel in NaCl as compared to corrosion rate in different sulphate and chloride content in with and without oxygen content. The corrosion rates are higher in solutions with oxygen content in all solutions. The hardness properties of carbon steel reduced after corrosion attack significant to weight loss of the materials. Furthermore, the weight loss value and hardness reduced is directly proportionate to corrosion rate. Figure 7 presents the corrosion rate performance of AISI 1040 in three different solutions namely; chloride (by using hydrochloric acid), sulphate (sulphuric acid) and sodium chloride (3.5% NaCl). All the solutions are in the same salinity and temperature. The corrosion rate increased as oxygen content increased as expected. However, the corrosion rate increased drastically (critical point) in sulphate and chloride solution which clearly explained that aggressive anions accelerate corrosion attack on carbon steel. Nevertheless, the corrosion rate is higher in chloride solution compared to sulphate which elucidate that chloride is more aggressive than sulphate in the same pH. The material’s performance was classified according to Equivalent Metric Rate Expression as showed in Table 2. It can be concluded that AISI 1040 can be categorized in the range of outstanding, excellent and good relative corrosion resistance material. The surface of samples AISI 1040 steel at highest dissolved oxygen concentration in solution more corrode than sample in the solution of the lowest dissolved oxygen concentration.

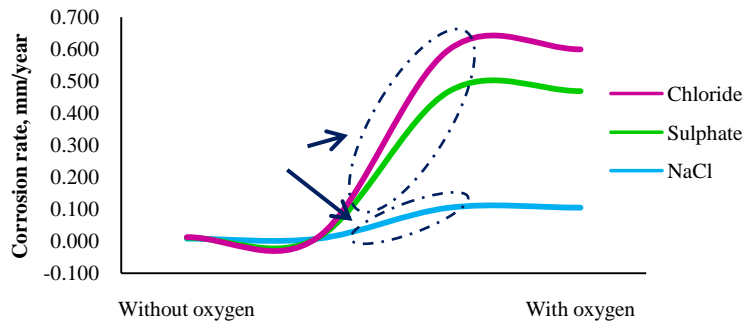


Figure 7: The critical corrosion rate

Table 2: Performance ranking of carbon steel

Solution	Oxygen content	Hardness Value (Hv)	Weight Loss (g)	Corrosion Rate (mm/y)	Relative Corrosion Resistance
NaCl	With	7.900	0.220	0.150	Good
	Without	5.800	0.090	0.008	Excellent
H <sub>2</sub> SO <sub>4</sub>	With	5.400	0.034	0.364	Good
	Without	3.500	0.010	0.0034	Excellent
HCl	With	6.900	0.020	0.1301	Good
	Without	1.600	0.000	0.0011	Outstanding

**III. ACKNOWLEDGEMENT**

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