American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-9, pp-87-95
www.ajer.org
Research Paper Open Access

Effects, Evaluation and Corrosion of Heat Exchangers Performance in Seawater

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ABSTRACT : *The durability of both aluminum and mild steel depends to a large extent on several factors prevailing in the operating environment. Among these factors are temperature and salinity. This paper therefore, investigates the impacts of temperatures and salt solutions on the corrosion rates of both aluminum and mild steel. The results obtained showed a significant effect of salt water and temperature as factors affecting the rate of corrosion. The results obtained as corrosion rates for aluminium at 35^{o}C ranges from 0.1862mmph - 0.2065 mmph and when the temperature rises to 65^{o}C, the range becomes 1.0567mmph – 1.994mmpy. Mild steel tested at 35^{o}C gives corrosion rates from 0.2145mmph – 0.5349 mmph while at 65^{o}C it ranged from 0.386mmph - 1.1771mmph. The results also proved that corrosion rates of these metal rise with decrease in salt (salinity) content as 0.05M NaCl concentration of the solution results to 0.1862mmph for aluminum and 0.2145mmph for mild steel at 35^{o}C and when the concentration of NaCl increases to 0.10M, the corrosion rates turned out to be 0.2065mmph for aluminum and 0.5349mmph for mild steel at same temperature. These results showed that temperature and salt content are two very significant properties needed to be paid attention to if corrosion is to be controlled.*
Key Words: *Heat Exchanger, Corrosion Rate, Seawater, Weight Loss.*

I. INTRODUCTION

Corrosion is a natural phenomenon, which can be considered either chemical or electrochemical in nature. It is defined as the deterioration or decay of metals by direct chemical attack or by reaction with its environment. [1] which may be referred to as rusting when iron is affected and tarnishing in the case of silver. Corrosion usually occurs when the environment's temperature goes above 0°C and the humidity is at 80% on a damp surface. The danger in corrosion is that it degrades the metallic properties of the affected metals [2]. Three essential elements necessary for corrosion to occur are: water, contaminants (e.g. salts) and oxygen [3].Corrosion of metals is costly and is a major aspect of material science as well as industrial problems that have attracted much investigations and researches [4]. Besides, the consequences of corrosion could also constitute safety, economic and technological problems.

Corrosion can be due to either atmospheric or immersion [3]. However, since heat exchangers are generally pressure vessels that convey fluids under high pressure and temperature, they are vulnerable to corrosion and scale formation. Acid pickling is a descaling process used for removing undesired scale, rust or other corrosion products from the surface of equipment such as boilers, heat exchangers [5]. The acid pickling processes which involve the application of acidic bath may impart severe damages to the metallic substrate [2][6] and as a consequence, the metals become prone to corrosion.

Extensive works have been carried out in ensuring that the rate at which corrosion affects industrial materials are controlled. [7] studied the effect of thiourea and its derivatives as corrosion inhibitors in acid media as well as the influence of temperature, hydrochloric acid and inhibitor concentration on MS. The study showed that thiourea is an excellent anodic inhibitor for MS in hydrochloric acid medium. The result also demonstrated that temperature and acid concentration increase the rate of corrosion. An investigative research carried out by [8] used weight loss technique on the corrosion effect of orange fruit juice on carbon steel. Coupons with known weights were immersed in the test tubes containing natural juice, orange juice as media with preservative and water for a total exposure time of 10days. From [9], the factors that influence the rate of corrosion in a shell and tube heat exchangers are:1) the pH of the fluid; 2) the amount of oxygen in the fluid; 3) the chemical make-up of the fluid; 4) the temperature of the fluid; 5) the velocity/pressure of the fluid in the pipe and 6) humidity.

The methods of corrosion, control measure depend on the type of corrosion and the factors affecting the particular corrosion [10, 11, 12, 13 and 14]. Therefore, having known the various types of corrosion and there effects, this paper is aimed at investigating seawater on heat exchangers constructed with Al or MS material and are subjected to working temperatures of 35°C to 65°C.

II. EXPERIMENTATION METHOD/TECHNIQUES

The method employed in this work to determine the effect of corrosion damages on metals is the weight loss method. The specimen also called coupon was weighed before it was exposed to the solvent. After exposing for a stipulated time, corrosion products on the metal were properly cleaned off and reweighed. The weight difference before and after exposure was the weight loss. From the weight loss the corrosion rate of the given specimen was calculated. The laboratory experimental procedure is outlined as follows:

a. Apparatus Used

The apparatus used were venier caliper, weighing machine, beaker, iron brush, file, sand paper or emery cloth, supporting iron rod and string. Metals specimens used for the test were aluminum and MS. While the solvent was Sodium chloride (NaCl) solution. Table 1 shows the shapes, sizes and areas of the specimen used for the experimentation.

TABLE 1: Shape, size and area of each specimen used.

Specimen	Shape	Size (mm)			Area (mm^2)
		Diameter	Width	Length	
Aluminium	Cylindrical	0.60	-	68	128.74
Mild steel	Cylindrical	3.00	-	68	655.02
Aluminium	Rectangular	-	1.60	68	108.80
Mild steel	Rectangular	-	3.80	68	258.40
Aluminium	Square	-	32	32	1024
Mild steel	Square	-	32	32	1024

b. Method of exposing specimens to solvents:

The specimens were exposed to the solvents in such a way as to reveal a large surface area of the specimen to the corrodents. Each coupon was suspended in a known volume (250ml) of corrosion media through a supporting rod and a thread. This was with a view to ensure uniform contact of the specimen with the medium as shown in fig. 2.

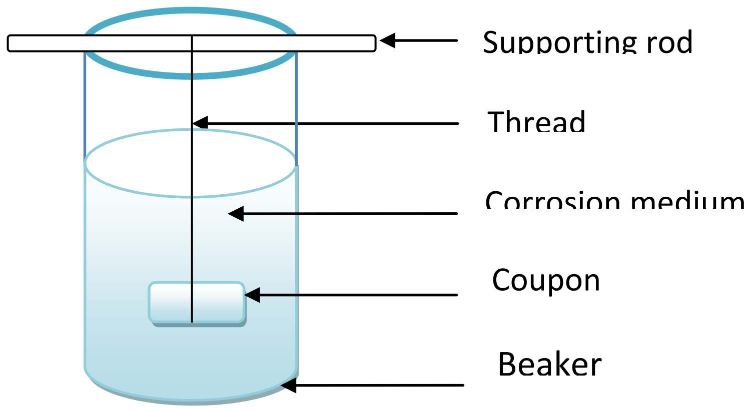

Fig. 2: Beaker Used as Corrosion Medium

Each Specimen was exposed first to the solvent at a concentration of 0.05M in a period of seven (7) days at temperature interval of 5°C with initial and final temperatures of 35°C and 65°C respectively. At the end of the seven days, the solvent concentration was increased to 0.10M and the same exposure method was repeated.

2.3 Preparation of Specimens for Reweighing:

This is another very important step in the laboratory procedures to determine the corrosion rate by weighing method. After exposing each metal for seven days (168 hours) at a particular temperature condition, the metal was brought out of the test solution.

2.4 Cleaning of corrosion products:

This method included scrubbing, scrapping and brushing. Surfaces of the metals were scrubbed with a very smooth emery cloth and brittle brush to remove the corrosion product.

2.5 Estimation of corrosion rates:

The test results can be referred to a unit of metal surface (mm^2 or cm^2) and sometimes (hour, day, year etc). Thus, corrosion rates are expressed in g/cm^2.hr or mg/mm^2.day. The corrosion resistance of a metal and the data obtained from the weight losses are converted into an index, which indicates the reduction in metal thickness. Such unit of corrosion resistance measurement is millimeter penetration per year (mmpy).

The corrosion rate expression using these units is given as follows:

$$Corrosion\ Rate\ (CR) \quad = \frac{Weight\ Loss(W) \times K}{(D)\frac{m_g}{mm^3} \times (A)mm^2 \times T} \qquad 1$$

Where

K = Rate constant (87.6)
W = weight loss in gram
D = density of metal in m_g/mm^3

A = Surface Area of metal in (mm^2)

T = Exposure time in hours

$$Corrosion\ rate\ (mmph) = \frac{87.6 \times W}{D \times A \times T} \qquad 2$$

2.6 Exposure time

Metal specimens were tested in inorganic solvent for a period of seven days (168 hours or 0.0192 year). Thus, in this work 0.0192 year is substituted for Time (T) in the rate expression.

2.7 Density of Specimen

Since cylindrical materials of known lengths and weight were used the densities were easily calculated. The densities of the various specimen used are calculated and tabulated using the formula.

Volume = πr^2L

Where,

L = known length of specimen in cm.

(Taking $\pi = \frac{22}{7}$)

$$Density = \frac{Mass(m_g)}{Volume(mm^3)} \qquad 3$$

D: Aluminium (Al) = $2.71mg/mm^3$

D: Mild Steel (MS) = $7.85mg/mm^3$

2.8 Area of Specimen

While the surface area of each coupon was calculated using:

$$Surface\ Area\ A = 2[(L\times B) + (B\times T) + (L\times T)] \quad 4\ [8]$$

Where,

L = Length of the coupon

B = Width of the coupon.

T = Thickness of the coupon.

D = Diameter of hole in coupon

III. RESULTS AND DISCUSSION

The original weights and the losses in weights as well as the corrosion rates data for aluminum and mild steel in sodium chloride solutions at different temperatures and concentrations are presented in tables 2 and 3 respectively as shown. Tables 2 and 3 clearly shows that the rates of corrosion rise with increase in temperature. A thorough examination and comparison of both tables also confirmed the fact that salt content (salinity) enhances the rate of corrosion as the higher corrosion rate for both specimen were recorded with 0.10M NaCl solution. A graphical demonstration of temperatures with the corrosion rates is as shown in fig. 3 illustrating the rise in temperatures with the corrosion rates for both specimen.

TABLE 2: Corrosion Rates Data for Specimen in 0.05 NaCl Solution

Weeks	T (°C)	Original Weight (mg)		Weight Loss (mg)		Al (Cylindrical)(mmph)	MS (Cylindrical)(mmph)	Al (Rectangular)(mmph)	MS (Rectangular)(mmph)	Al (Square) (mmph)	MS (Square) (mmph)
		Al	MS	Al	MS						
Days 1	35	7837	15637.60	0.092	1.562	0.00066	9.836E-06	1.25E-08	1.337E-05	2.53E-10	0.00064
2	40	7837	15637.60	0.172	1.812	0.0010797	1.141E-05	2.05E-08	8.299E-06	3.57E-10	0.000243
3	45	7837	15637.60	0.244	2.022	0.0013614	1.273E-05	2.59E-08	6.528E-06	4.04E-10	0.000151
4	50	7837	15637.60	0.33	2.202	0.0016572	1.387E-05	3.15E-08	5.256E-06	4.51E-10	0.0001
5	55	7837	15637.60	0.398	2.402	0.0018169	1.513E-05	3.45E-08	4.754E-06	4.54E-10	8.26E-05
6	60	7837	15637.60	0.489	2.652	0.0020463	1.67E-05	3.89E-08	4.272E-06	4.63E-10	6.59E-05
7	65	7837	15637.60	0.522	2.812	0.0020164	1.771E-05	3.83E-08	4.243E-06	4.3E-10	6.64E-05
Second 1	35	7837	15637.60	0.612	3.042	0.0043904	1.916E-05	8.34E-08	3.915E-06	8.66E-10	2.82E-05
2	40	7837	15637.60	0.649	3.252	0.0040739	2.048E-05	7.74E-08	3.947E-06	7.51E-10	3.06E-05
3	45	7837	15637.60	0.683	3.422	0.0038109	2.155E-05	7.24E-08	3.947E-06	6.68E-10	3.27E-05
4	50	7837	15637.60	0.708	3.622	0.0035554	2.281E-05	6.75E-08	4.03E-06	5.89E-10	3.58E-05
5	55	7837	15637.60	0.727	3.792	0.0033189	2.388E-05	6.31E-08	4.109E-06	5.25E-10	3.91E-05
6	60	7837	15637.60	0.75	4.012	0.0031386	2.526E-05	5.96E-08	4.214E-06	4.69E-10	4.24E-05
7	65	7837	15637.60	0.922	4.192	0.0035615	2.64E-05	6.77E-08	3.581E-06	5.1E-10	3.17E-05

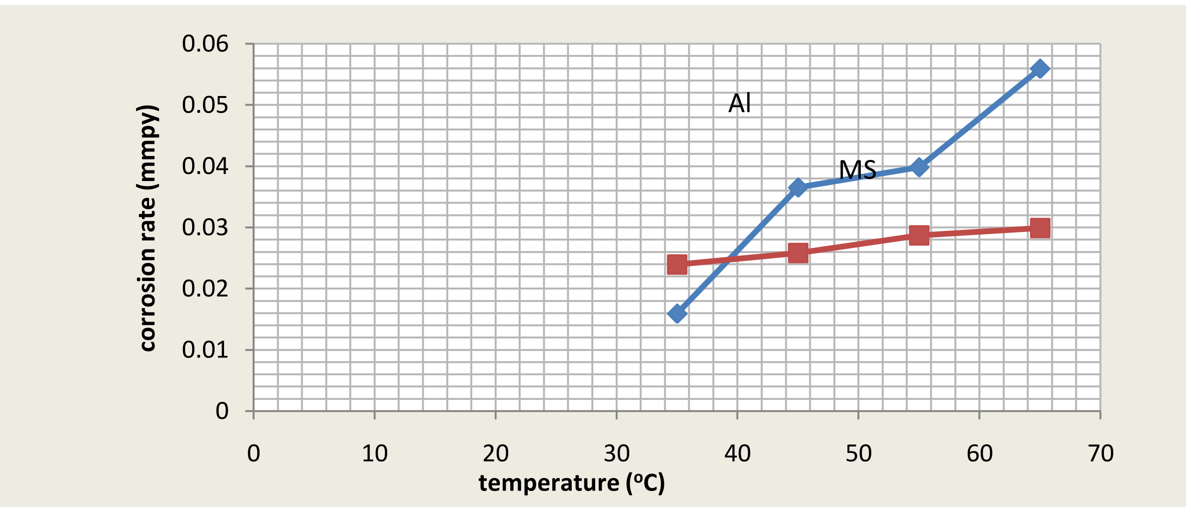

Fig. 3: Graphical illustration of Corrosion Rate Against Temperature Variations for Al and MS.

Fig. 3 showed the effect of temperature variations on corrosion rates for both aluminium and mild steel. The graph proved that as temperature changes from 35°C to 65°C, the corrosion rates of the metals increase as demonstrated in the case of both Al and MS that rose in from low to high. This affirms that corrosion rate is lower at room temperature than boiling temperature [15].

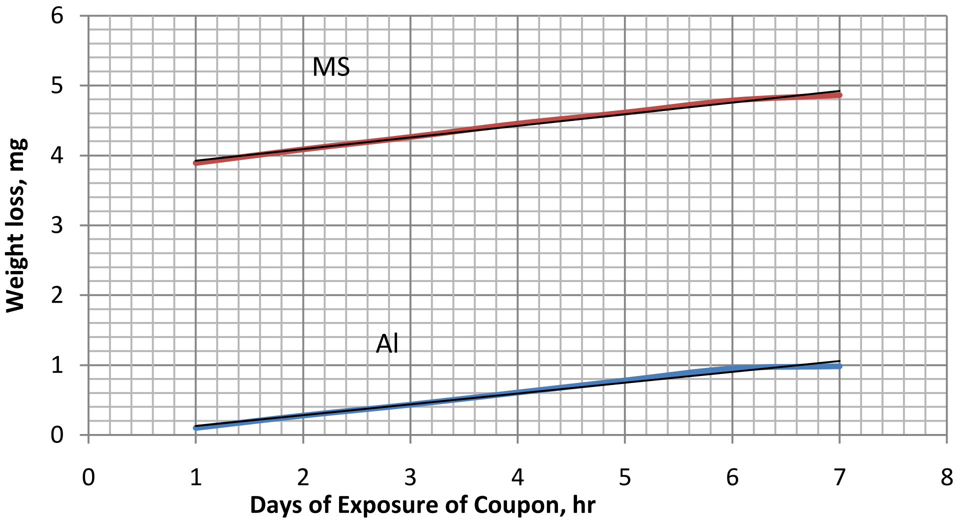

Fig. 4: Effect of time on the weight loss of MS and Al for the first seven days of exposure to 0.05 NaCl Solution

The effect of immersion time and the weight loss of both specimen in sea water was studied. From the gradual increases in loss in weight from 0.092mg to 0.522mg and 1.562mg to 2.812mg for Al and MS respectively, as clearly illustrated in fig 4, where it was shown that as the coupon was kept for a longer periods in the 0.05M NaCl solution, the extent of corrosion of the metals becomes deeper.

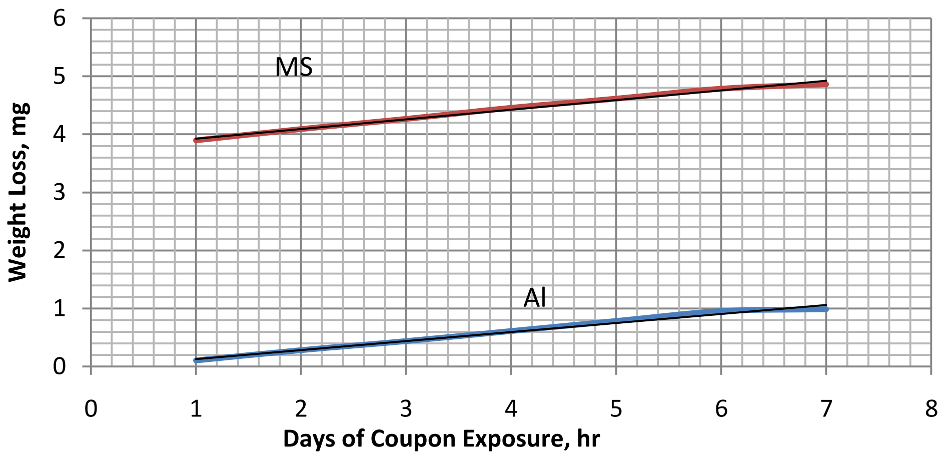

Fig. 5: Effect of time on the weight loss of MS and Al for the second seven days of exposure to 0.05 NaCl Solution

Fig. 5 is a repeat of the exposure time versus the weight loss method. However, this was done for another seven days at the end of the first seven days in which the first experiment was carried out. This, once again, confirms the interdependence of exposure time and weight loss. It was demonstrated to further affirm the effect of the exposure time on both specimen in 0.05M NaCl solution.

TABLE: Corrosion Rates Data for Specimen in 0.10 NaCl Solution

Weeks	Temp. (°C)	Original Weight (mg)		Weight Loss (mg)		Al (mmph)	MS (mmph)	Al (mmph)	MS (mmph)	Al (mmph)	MS (mmph)
		Al	MS	Al	MS						
Days 1	35	7837	15637.60	0.1	3.894	0.00073	2.5E-05	1.4E-08	3E-05	1.1E-10	0.0013
2	40	7837	15637.60	0.28	4.088	0.00175	2.6E-05	3.3E-08	1.2E-05	2.6E-10	0.00021
3	45	7837	15637.60	0.44	4.264	0.00243	2.7E-05	4.6E-08	7.7E-06	3.4E-10	0.0001
4	50	7837	15637.60	0.61	4.455	0.00306	2.8E-05	5.8E-08	5.8E-06	4.1E-10	5.9E-05
5	55	7837	15637.60	0.78	4.613	0.00357	2.9E-05	6.8E-08	4.6E-06	4.6E-10	4.1E-05
6	60	7837	15637.60	0.95	4.785	0.00399	3E-05	7.6E-08	4E-06	5E-10	3.1E-05
7	65	7837	15637.60	0.99	4.862	0.0038	3.1E-05	7.2E-08	3.9E-06	4.7E-10	3.2E-05
Second 1	35	7837	15637.60	1.16	4.97	0.00832	3.1E-05	1.6E-07	3.4E-06	1E-09	1.3E-05
2	40	7837	15637.60	1.34	5.161	0.00838	3.2E-05	1.6E-07	3E-06	9.7E-10	1.1E-05
3	45	7837	15637.60	1.48	5.298	0.00828	3.3E-05	1.6E-07	2.8E-06	9.4E-10	1.1E-05
4	50	7837	15637.60	1.63	5.452	0.00818	3.4E-05	1.6E-07	2.6E-06	9E-10	1E-05
5	55	7837	15637.60	1.78	5.634	0.00811	3.5E-05	1.5E-07	2.5E-06	8.6E-10	9.7E-06
6	60	7837	15637.60	1.94	5.824	0.0081	3.7E-05	1.5E-07	2.4E-06	8.3E-10	9.2E-06
7	65	7837	15637.60	2.06	5.95	0.00797	3.7E-05	1.5E-07	2.3E-06	8E-10	9E-06

The exposure time and weight loss procedure was again studied while the NaCl solution was increased to 0.10M. And as seen in fig. 6, the weight loss increases from 0.10mg and 3.894mg to 0.99mg and 4.862mg respectively for both Al and MS. This showed that Al as a common component ship superstructures and liquid cargo containers and heat exchangers are susceptible to corrosion due to their continual exposure to sea environment [16].

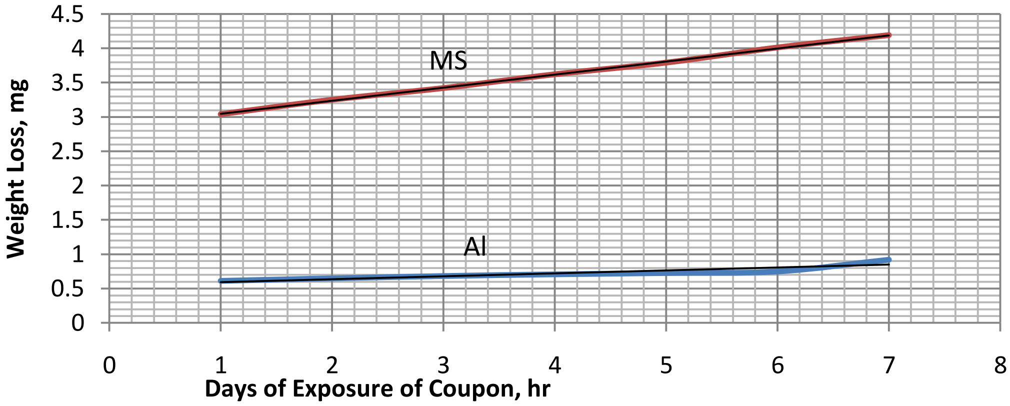

Fig. 6: Effect of time on the weight loss of MS and Al for the second seven days of exposure to 0.10 NaCl Solution.

Fig.7 is a demonstration of same procedure as in fig. 6, the difference being that the test specimen in the 0.10M NaCl solution was being observed for another seven days outside the seven days in which the initial procedure was subjected to. The results of this second experimentation as illustrated in fig. 7 shows that the weight loss against the exposure time clearly follows the pattern of fig. 6, 1.16mg and 4.97mg to 2.06mg and 5.95mg.

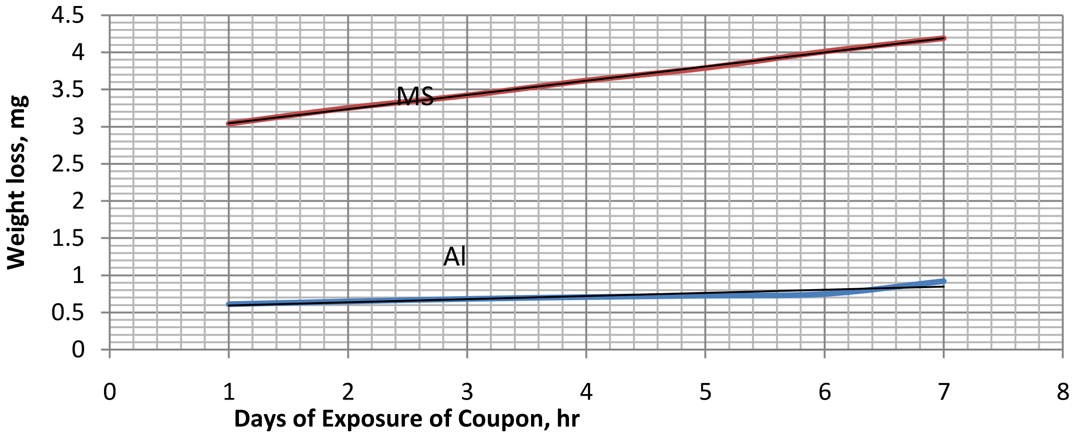

Fig. 7: Effect of time on the weight loss of MS and Al for the first seven days of exposure to 0.10 NaCl Solution.

The corrosion rate data obtained from the experimental work gave general information on the behavior of aluminium and MS in corrosive environment. For example, both the aluminium and MS tested showed a general high corrosion rate at increased temperatures with change in the salt content of the solution.

IV. CONCLUSION

In view of the usefulness and importance of both aluminum and MS and also the environmental conditions of the areas in which these very important metals will have useful applications, a study was carried out to determine the impacts of temperatures and salinity on the corrosion rates of these metals. The study affirmed that higher temperature and salt solution could result to corrosion rates of 1.1994mmph and 1.1771mmph for aluminum and MS respectively.

- For aluminium at 35^{o}C, the corrosion rate ranged from 0.1862 - 0.2065 mmph while at 65^{o}C, it ranged from 1.0567 – 1.994mmph
- MS tested at 35^{o}C gave corrosion rates from 0.2145mmph – 0.5349mmph while at 65^{o}C it ranged from 0.3862mmph – 1.1771mmph.

V. RECOMMENDATIONS

Based on the results obtained in this research work, the recommendations are as follows:

1) The coating system should be correctly used in conjunction with the anti-corrosion resins.
2) Consideration should be given to material selection for long time corrosion control.
3) All metals for marine application should be given a proper attention with proper periodic monitoring and cleaning.

Acknowledgement : The authors wish to heartily acknowledge Mr Calaba for his relentless effort in the running of the experiments. The enthusiasm displayed in collecting, verifying and authenticating the data is equally appreciated.

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