LAUTECH JOURNAL OF ENGINEERING AND TECHNOLOGY 1(1) 2003: 75-81

PREDICTIVE MODEL FOR EVALUATING CORROSION RATE OF MILD STEEL IN SIX ENVIRONMENTS

Adebiyi*, K.A., Hameed, K.A. and Ajayi, E.O.

***Department of Mechanical Engineering, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Oyo State, Nigeria**

*** Corresponding Author: E-mail engradebiyi@ yahoo.com**

ABSTRACT

Experiments were carried out in six environments for 90 days to determine the levels of corrosion rates on AISI 1021 mild steel rods. The environments were: Sodium hydroxide fumes; Sulphuric acid fumes; Nitric acid fumes; Sodium sulphate fumes; Sodium Chloride solution; and Water from borehole. Weight losses in the rods were determined at intervals of 5 days as these rods were exposed to the environments The relationships between loss in weight of the exposed steel and exposure period were determined. Corrosion rate models were developed as a function of total surface area and exposure period. The theoretical corrosion rates were compared to rates determined from theoretical considerations.

It was found that the corrosion effect is rapid in Na0H environment. Its effect was noticed after about 2 hours of exposure. The samples exposed to Sulphuric acid fumes environment had the highest mean corrosion rates of 0.5488 cm/yr (for established) and 0.5201 cm/yr (for predicted). Water from borehole environment had the least mean corrosion rates of 0.1249 cm/yr (for established) and 0.1277 cm/yr (for predicted). There is no significant difference between the calculated values of corrosion rates using established model and predictive models, thus indicating the reliability of the models.

Keywords: Experiments, Corrosion Rate, Modeling, Environments

INTRODUCTION

Metals in general, and mild steel in particular, are affected by corrosion in many different ways, ranging from uniform dissolution of the material as it is exposed to an environment, to highly localized pitting or cracking. The general types of corrosion have been identified to include electrochemical, galvanic, concentration cell, erosion, embrittlement, stress corrosion, filaform, corrosion fatigue, intergranular, fretting, impingement, dezincification, and chemical reaction. [Schouten and Gellings 1987, RxN Communications 2002, Shawla and Gupta 1993, Scully 1984].

Corrosive chemical compounds, pesticides, salts, weak acids and sterilizing chemical solution for cleaning purposes are among materials identified as corrosion causing agents [Schouten and Gellings, 1987]. The undesirable results of corrosion range from leakage, and total fracture of the component concerned to contamination of the product being handled by the equipment. The resulting effects may be health hazards. It was reported that about $70 billion is lost annually as a result of corrosion in the United States of America [Paul, 2000]. While it is likely to be much less in Nigeria, it is still a major country that has to be addressed.

One of the most important issues in current day corrosion research is the assessment of corrosion rates and corrosivity of typical operating environments. Corrosion rate is affected by type of surface of metal, surface area, period of exposure, pressure gradient, temperature, presence of carbon – dioxide and water- cut [Jepson et al 1996, Sodiki 2002]. According to Jangama and Srinivasan (1996) corrosion rate if kept low, increases safety and profitability.

Numerous predictive models have been developed and are still being developed for corrosion rate determination. Most of the available models tend to be either too conservative in their interpretation of results or to focus on industrial applications without much concern for domestic applications.
For example, Jepson et al (1996) developed a predictive model that relates the corrosion rate to the pressure gradient, temperature, carbon dioxide, partial pressure and water cut as applicable to corrosion in horizontal multiphase slug flow in low viscousity oil.

Srinivasan et al (1996) developed a predictive model that utilizes commonly available operation parameters. An example is CO_2 /H_2S in oil and gas production environments from a standpoint of defining limits of use of carbon steel. A critical investigation into Corrosivity of metal in various environments will assist in determining the associated problems so as to prevent excessive losses and health hazard that may result. Also, it is frequently necessary to know how a specific material will behave in a given environment to determine the service life of the material in such environment.

This paper deals with the development of predictive models for determining the corrosion rate of mild steel in six different environments (Water from Borehole, NaCl, Na_2SO_4, H_2SO_4 NaOH and HNO_3). The investigation involved experimentally determining weight losses of metals within the environments; utilizing the laboratory data and a theoretical model to obtain a realistic assessment of corrosivity and corrosion rate with particular preference to duration of exposure and surface area exposed.

MATERIALS AND METHOD

(a) Experimental Set up and Procedure

Six mild steel specimens 4cm in length, 2cm in width and 0.1cm thick were used for the experiment. A hole of 0.1cm diameter was drilled on each of the specimen for ease of hanging in the media by string. According to Sodiki (2002), surface finish affects the corrosion rate. Therefore, the specimen surface was cleaned with emery cloth of grade 220; rinsed with distilled water and degreased in ethanol. The specimens were then etched in 5% HCl for about 30 seconds and immediately rinsed for 60 seconds to wash off the excess acid and they were finally mopped with filter paper before being exposed to the test media.

Sodiki (2002) reported that among the widely use corrosion measurement techniques, weight change determination was preferred due to its simplicity. In this study the investigation involved periodic weight loss measurement. The specimens were etched in the media for 90 days. The loss in weight was checked at intervals of 5 days. The results of the experiment are plotted as shown in Fig 1.

(b) Model Formulation

Developing the model utilizes the result of the experiment and existing theoretical model to obtain an assessment of Corrosion rate. According to Scully (1984), the corrosion rate of a metal in a medium is given by:

$$R = \frac{534W}{\rho t A} \text{ cm/yr} \quad \text{(i)}$$

Where:

R – Corrosion rate in cm/yr

W – Weight loss in gm

ρ – Density in kg/cm³

t – Time in hours

A – Total surface Area in Cm²

Graphs of weight losses against exposure periods were plotted as shown in Fig.1. Regression of loss in weight on exposure period was determined. Based on the pattern of graphs in Fig.1 the regression equation employed is of the form.

$$W_i = a_i + b_i x \quad \text{----------} \quad \text{(ii)}$$

Where:

W_i - loss weight of mild steel in medium i (mg)

x - Exposure period (days) a_i, and b_i are constants

Substituting equation (ii) in (i) gives

$$R_i = \frac{534(a_i + b_i x)}{\rho_{ms} A\, t} \quad \text{(iii)}$$

Converting period of exposure t into day by dividing t by 24 gives

$$R_i = \frac{1281b(a_i + b_i x)}{\rho_{ms} A\, x} \quad \text{(vi)}$$

$$\Rightarrow R_i \frac{12816}{\rho_{ms} A}(a_i x^{-1} + b_i) \quad \text{(v)}$$

A regression analysis of the values of W (x) was carried out on the experimental data to evaluate the values of constants a_i and b_i. These values are given in Table 2. Using equation (v), Table 2 and density of mild steel, the resulting predictive models for the media are:

$R_{borehole} = 1.6305A^{-1} [4.9328x^{-1} + 0.4351]$

$R_{Nacl} = 1.6305A^{-1} [1.0908x^{-1} + 0.8423]$

$RN_{a2}s0_4 = 1.6305A^{-1} [2.4834 - 8.5103x^{-1}]$

$R_{NaOH} = 1.6305A^{-1} [2.4720 - 4.220x^{-1}]$

$R_{H2SO4} = 1.6305A^{-1} [2.6597 - 3.758x^{-1}]$

$R_{H}NO_3 = 1.6305A^{-1} [2.5048 - 3.458x^{-1}]$

RESULTS

The models were used to predict the corrosion of mild steel as a function of surface area and exposure period. The six media used and their corresponding concentrations and pH values are listed in Table 1. The media used have wide industrial and domestic applications. The surface area of each of the specimens was 8cm² while the exposure period ranged from 5 days to 90 days. The results of predicted values and established values were plotted for each of the media as shown in figures. 2, 3, 4, 5, 6 and 7. The variability between the predicted values and established values are shown in Table 4.

DISCUSSION

Effect of Environments on Corrosivity of Mild Steel

(i) **Water from Borehole.** About 24 hours after immersion, the steel surface became dull and bubbles were forming on the specimen, which later gave way to a faint greenish colouration at the surface. This continued progressively and the colour later turned brownish. However, very little deposit of brown particles settled in the bottom of the beaker at the end of 90th day and the mean weight loss was 5.11mg.

(ii) **Salt Water (NaCl):** Brownish colouration was noticed on the specimen surface after two days' exposure. This remained till about the 58th day and the medium became cloudy. Around the 60th day, the specimens turned yellowish brown and later became brownish till the end of 90th day with more deposits than samples found in the samples immersed in borehole water medium. The mean weight loss was 8.21mg.

(iii) **H_2SO_4 solution**: Few hours after immersion, bubbles were seen on the specimen and the specimen later turned greenish with brown particles at the bottom of beaker. After about 27 hours, the green colour changed to brown and later to yellowish brown about 38 hours after immersion, with more particles being deposited. The situation progresses until about the 45th day when the solution changed to pale yellow with the specimen becoming reddish brown. At about the 70th day, the specimen changed brownish completely and continued till the end of 90th day with more particles being deposited and mean weight loss is 24.9 mg.

(iv) **NaOH Solution**: After about 2 hours of immersion, the solution started changing colour, with green patches on the specimen which gradually turned brown. After about 19 hours the solution became reddish brown and later turned yellowish brown after about 33 hours of exposure with appreciable deposit of brown particles. The yellowish brown intensity increased continually till the end of 75th day after which the solution turned reddish brown and after words brownish till the end of 90th day. The mean weight loss is 22.6 mg.

(v) **HNO_3 Solution:** After about 10 hours of immersion, the specimen started turning green and later brownish. After 35 hours, the solution changed to pit brown. The colouration changed progressively, turning reddish brown after 65th day. Afterwards, the specimens turned completely brown ill the end of 90th day with brown particles deposit with mean weight loss of 23. 44mg.

(vi) **Na_2SO_4 Solution**: Brownish colouration as noticed after about 40 hours of immersion. The brownish colouration continued progressively till the end of 90th day with deposit of brown particles with mean weight loss of 21.3mmg.

Effect of Environment on Corrosion Rate

The corrosion rate of mild steel varied with the environment of exposure. The mean corrosion rate using theoretical model varied from 0.1249 cm/yr (for water from borehole) to 0.5488 cm/yr (for H_2SO_4) as shown in Table 3. For predictive models, the mean corrosion rates vary from 0.1277 cm/yr (for water from borehole) to 0.5201 cm/yr (for H_2SO_4) as shown in Table 3. The differences between the predicted corrosion rate and established corrosion rates notwithstanding, both the established and predicted model curves follow the same trend for each environment as shown in Figures 2, 3, 4, 5, 6 and 7. Results of statistical analyses shown in Table 4 suggest that there is no significant difference between the established values and predicted values thereby validating the reliability of the predictive models.

CONCLUSIONS

The following can thus be deduced:

(i) Corrosivity effect of mild steel is fastest in NaOH environment is the highest among the six environments considered.

(ii) Corrosion rate is more pronounced in acidic environment. The H_2SO_4 environment has the highest corrosion rate with mean corrosion rate of 0.5488 cm/yr (established) 0.5201 cm/yr (predicted) followed by HNO_3 0.5301 cm/yr (established) 0.4903 cm/yr (predicted); NaOH 0.4781 cm/yr (established) 0.4705 cm/yr (predicted); Na_2SO_4 0.4415 cm/yr (established) 0.4288 cm/yr (predicted); NaCl 0.1864 cm/yr (established) 0.1803 cm/yr (predicted) and Borehole H_2O 0.1249 cm/yr (established) 0.1277 cm/yr (predicted).

(iii) The developed predictive models give more reliable assessment of corrosion rate in terms of total surface area and exposure period when compared to the theoretical model.

Table 1: The Media use with Their Corresponding Concentration and pH

	Medium	pH	Concentration (mol/dm^3)
1.	Bore hole water	6.3	3.162×10^{-4}
2.	Salt water	7.3	3.162×10^{-4}
3.	Tetra oxo sulphate	4.5	20 10^{-4}
4.	Sodium Hydroxide	8.5	3.162×10^{-4}
5.	Nitric Acid	4.8	20 10^{-4}
6	Sodium Sulphate	6.9	3.162×10^{-4}

Table 2: Regression Coefficients of Weight Loss Against Exposure Period

Medium (i)	a_i	b_i
Borehole	4.9328	0.4351
Nacl	1.0908	0.8423
Na_2SO_4	– 8.5103	2.4339
NaOH	– 4.220	2.4720
H_2SO_4	– 3.7883	2.6987
HNO_3	– 3.4880	2.5408

Table 3: Means of Theoretical and Predicted Corrosion Rates

Environment	Water from Borehole	NaCl	Na_2SO_4	NaOH	H_2SO_4	HNO_3
Theoretical Corrosion Rate (cm/yr)	0.1249	0.1864	0.4415	0.4781	0.5488	0.5031
Predicted Corrosion Rate (cm/yr)	0.1277	0.1803	0.4285	0.4705	0.5201	0.4903

Table 4: Results of t–test of Theoretical and Predicted Corrosion Rates at 5% Significant Level

Environment	Borehole H_2O	NaCl	Na_2SO_4	NaOH	H_2SO_4	HNO_3
T–value Calculated	0.2090	0.6854	0.6468	0.7755	1.3411	1.1636

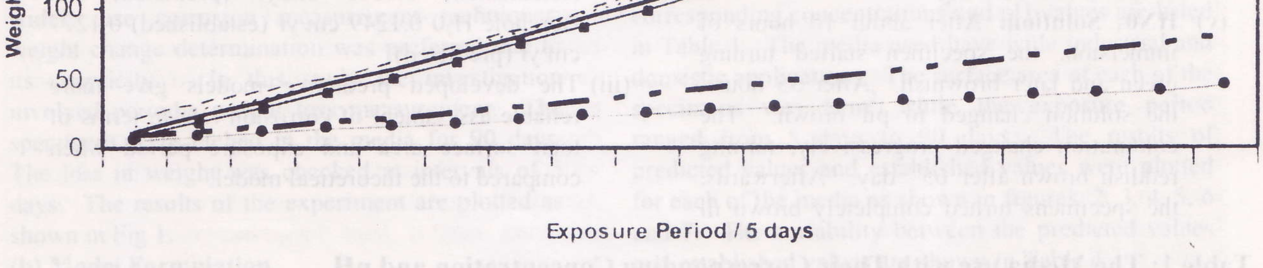

Fig 1. Weight Loss Vs Exposure period

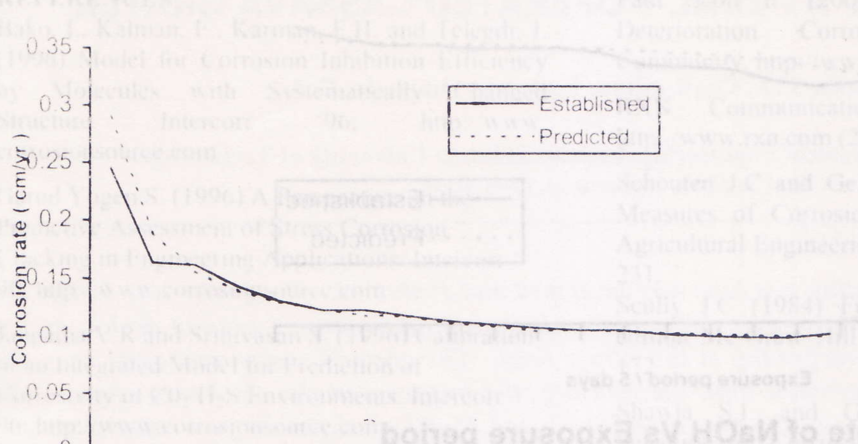

Fig. 2. Corrosion rate of water from borehole Vs Exposure period

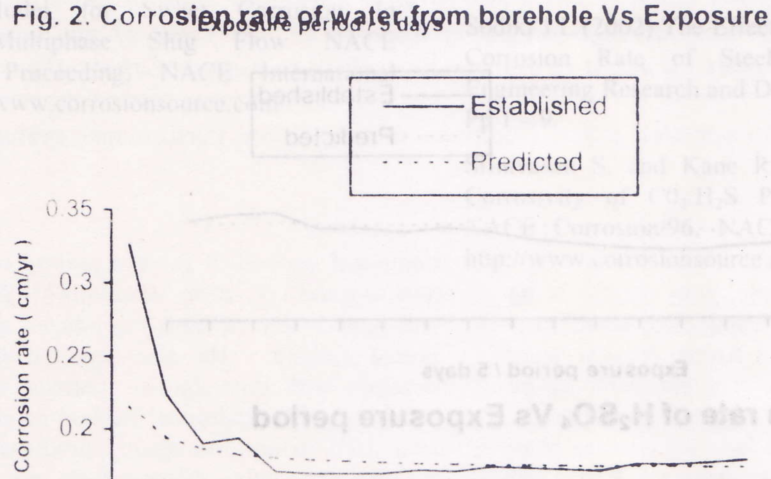

Fig. 3. Corrosion rate of NaCl Vs Exposure period

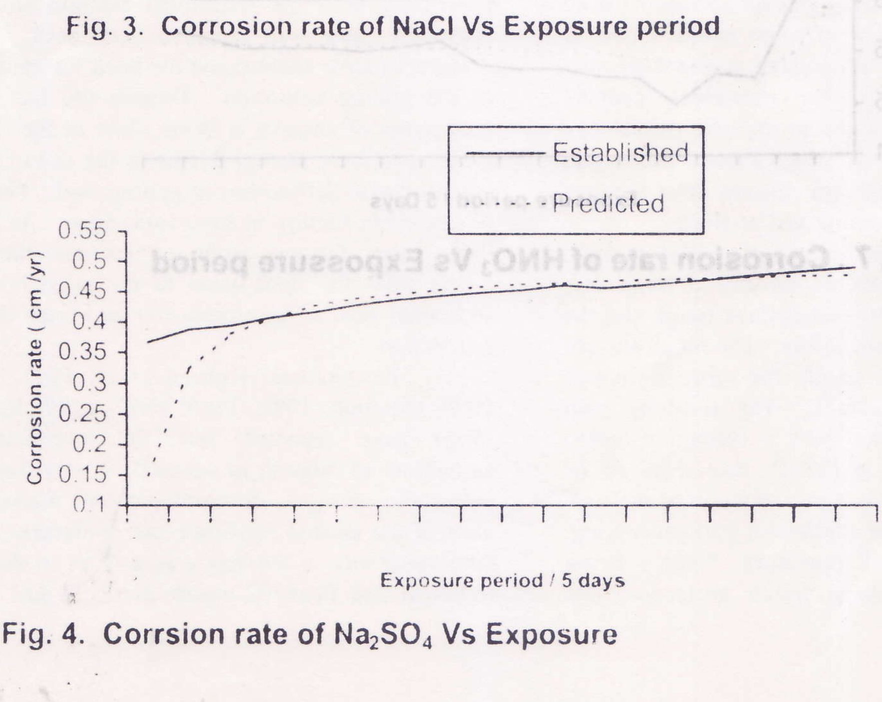

Fig. 4. Corrsion rate of Na_2SO_4 Vs Exposure

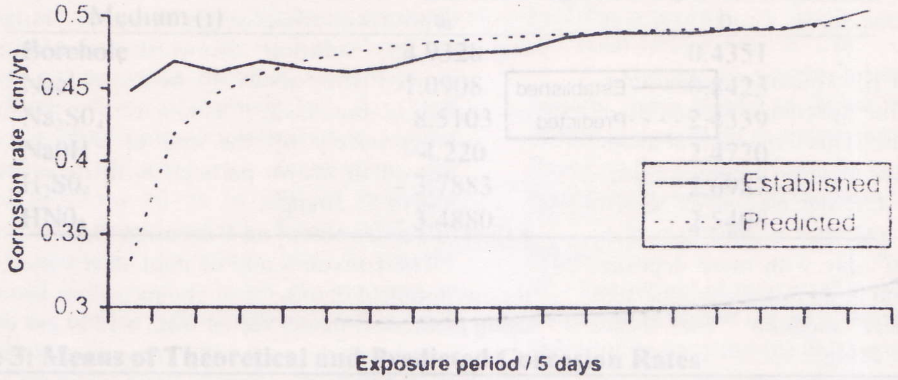

Fig. 5. Corrossion rate of NaOH Vs Exposure period

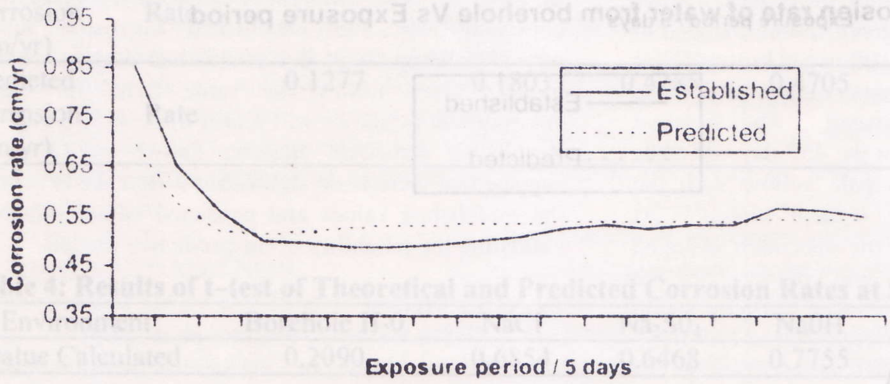

Fig. 6. Corrosion rate of H_2SO_4 Vs Exposure period

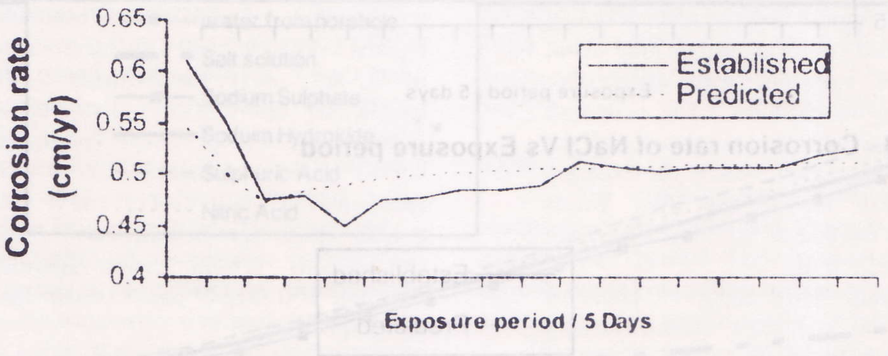

Fig. 7 . Corrosion rate of HNO_3 Vs Expossure period

REFERENCES

Bako, I., Kalman, E., Karman, F.H. and Telegdi, J. (1996) Model for Corrosion Inhibition Efficiency by Molecules with Systematically Changed Structure. Intercorr '96: http: www. corrosionsource.com

Garud Yogen S. (1996) A Perspective on the Predictive Assessment of Stress Corrosion Cracking in Engineering Applications. Intercorr '96: http: www.corrosionsource.com

Jangama V.R and Srinivasan S. (1996) Calibration of an Integrated Model for Prediction of Corrosivity of CO_2H_2S Environments. Intercorr 96: http://www.corrosionsource.com

Jepson P, Bhongale S and Gopal M (1996) Predictive Model for Sweet Corrosion In Horizontal Multiphase Slug Flow NACE corrosion/96 Proceeding, NACE International Denver http://www.corrosionsource.com

Paul Scott tt. (2000) Minimizing Infrastructure Deterioration. Corrosion Journal for Online Community, http://www.corrosioneeringjournal.Htm

RXN Communications Types of Corrosion http://www.rxn.com (2002).

Schouten J.C and Gellings P.J (1987). Quantitative Measures of Corrosion in Agriculture" Journal of Agricultural Engineering Research. Vol. 36 pp 217 – 231.

Scully J.C (1984) Fundamentals of Corrosion 3rd edition Mc-Graw Hill Book Co., New York pp149-172

Shawla S.L and Gupta R.K (1993) Materials Selection for Corrosion Control ASM International. New York pp47-61

Sodiki J.L (2002) The Effect of Surface Finish on the Corrosion Rate of Steel Nigerian Journal of Engineering Research and Development, Vol. 1, No 2 Pp 1 – 9.

Srinivasan S. and Kane R.D (1996) Prediction of Corrosivity of CO_2/H_2S Production Environments NACE Corrosion/96, NACE International, Denver http://www.corrosionsource.com.