

## Experimental Investigations and Mathematical Modelling of Corrosion Growth Rate on Carbon Steel under the Influence of Soil pH and Resistivity

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**Abstract:** - Experiments were conducted to investigate the correlation of soil properties towards metal loss of API 5L X42 carbon steel coupons, with emphasis on soil pH and resistivity. A total of four pieces of X42 coupons were placed in four soil samples gotten from four different states within the Niger Delta region for 2352 hours, to study the influence of soil properties towards metal loss via weight loss method. The soil coupons were buried in the soil samples placed in a plastic container, allowed to corrode naturally and then retrieved every 168 hours. Results showed that both parameters had an influence on buried steel but soil resistivity value had a dominating influence compared to soil pH. It was also observed from the ANOVA that, soil resistivity had a major contribution to corrosion reaction in soil. A mathematical model is also developed using multiple regression analysis. The result indicated that the model developed was suitable for prediction of corrosion growth rate with soil pH and resistivity as the two independent variables. Since the coefficient of determination  $R^2 = 0.8129$  was significantly high, the predicted and measured values also were fairly close to each other.

**Keywords:** *Underground Corrosion, Soil, carbon Steel, pH, mils per year (MPY)*

### I. INTRODUCTION

This study is the outgrowth of continuing interest throughout the oil industry, especially in the oil rich part of Nigeria in a bid to reducing the incidence of oil spillages caused by corrosion. This involves identifying the key processes and environmental conditions which mostly influences the equipment deterioration rate. Once identified, a strategy is established to routinely monitor these key processes and environmental parameters and maintain them within prescribed limits to control corrosion or material deterioration to acceptable levels (Mbamalu & Edeko, 2004). The word corrosion is derived from the Latin *corrosus* which means eaten away or consumed by degrees; an unpleasant word for an unpleasant process (Syed, 2006). As such, when corrosion is being discussed, it is important to think of a combination of a material and an environment. The corrosion behaviour of a material cannot be described unless the environment in which the material is to be exposed is appropriately identified. Similarly, the corrosivity or aggressiveness of an environment cannot be described unless the material that is to be exposed to that environment is also identified. Summarily therefore, the corrosion behaviour of the material depends on the environment to which it is subjected, and the corrosivity of an environment depends on the material exposed to that environment. Soil which is the electrolyte is a complex environmental material which has made the study of corrosion in carbon steel vague. However, understanding the physicochemical composition of soil is a key to unravelling how a soil can influence corrosion reaction. It has become expedient that operators should examine every particular site to explain the corrosion mechanisms models resulting from the steel interaction with the soil environment which depends on several factors such as soil type, moisture content, soil resistivity soil pH, oxidation – reduction potential and microbial load.

### II. LITERATURE SURVEY

Some investigators have carried out extensive experiments as regards the corrosion rate of steel and its interactions with soil parameters. It has been reported that soil resistivity is by far the best criterion for estimating the corrosivity of a given soil in the laboratory, where the vital parameter of moisture can be controlled (Dayal and others, 1988). In their work, they studied a number of Indian soils so as to identify a link between the different soil properties and its corrosivity to the underground metallic structures. Microbiologically influenced corrosion (MIC) of carbon steel exposed to anaerobic soil and in model soil has been investigated respectively by Li and others (2001) and Hirfumi and others (2003). Rim-rukeh and Awatefe (2006) studied the corrosion of a 10 inch crude oil pipeline by analyzing the physicochemical characteristics of the soil environment. The study of soil concentrations, pH, temperature and other

important soil parameters showed it to be clay soil environment. The corrosivity of the soil samples were evaluated using AWWA C-105 numerical scale. A total sum index of 21 recorded implied that the soil tested was extremely corrosive for low carbon steel.

Maslehuddin and others (2007) studied the just effect of chloride concentration in soil on the corrosion behaviour of reinforcing steels.

Also Sjögren and others (2007) in their work aimed at clarifying the resistance against external corrosion of stainless steel pipes in soil. The core of the project was actually done in-situ and the specimens buried in soil both in Sweden and in France.

Study on the mechanical properties of steel in aqueous corrosion showed that losses in mechanical properties for specimens exposed to sea water were higher than those exposed to fresh water for every properties tested (Cho, 2010). Fang and others (2010) conducted a research to investigate the effect of a high salt concentration on corrosion from low partial pressures of hydrogen sulfide (H<sub>2</sub>S). The main objective was to study if the high concentration of chloride could initiate localized attack in this type of H<sub>2</sub>S system. Their experimental results revealed that a high salt concentration significantly slowed down the reaction rate in H<sub>2</sub>S corrosion. The effect of pH value to corrosion growth rate on API 5L X70 low carbon steel exposed to soil condition was studied by Farah (2011).

Noor and others (2012) investigated the relationship between soil properties and corrosion of carbon steel. The test focussed on three types of major soil engineering properties towards metal loss of X70 carbon steel coupons. The three properties soil properties were moisture content, clay content and plasticity index. It was found that the soil moisture content had a more observable influence towards corrosion more than clay content and plasticity index. Cunha Lins and others (2012) conducted a similar experiment with the aim of evaluating the corrosion resistance of the API 5L X52 steel in soil from the Serra do Ouro Branco and Minas Gerais in Brazil. According to their result findings, a corrosion product layer of iron oxide/hydroxide was identified on the surface of steel.

Bhattarai (2013) in his work focussed to investigate soil parameters such as moisture content, pH, resistivity, oxidation-reduction potential, chloride and sulphate contents on the corrosivity of buried-galvanized steels and cast iron pipelines in an attempt to specify the corrosive nature of soils in Panga-kirtipur-Tyanglaphant areas of Municipality. Corrosion behaviours of Q235 steel in indoor soil for 21 days and the soil parameter being moisture content has also been investigated by Wan and others (2013). In essence they stated that moisture had a noticeable influence on corrosion of steel.

Zenati and others (2013) researched on the corrosion of C-Mn steel type API X60 in simulated soil solution environment and inhibitive effect. The main objective of their investigation was to study the susceptibility interactions of steel with the soil environment. Okiongbo and Ogobiri (2013), investigated soil corrosivity along a pipeline route in the Niger Delta Basin (along the Obrikom-Ebocha areas) using Geoelectrical method. The test was conducted to predict the corrosivity of the top three meters of the soil along a slumberger pipeline route using soil electrical resistivity as the parameter.

Therefore, this research is carried out to investigate the relationship between soil pH and resistivity towards carbon steels and also develop a suitable model for the relationship.

### **III. MATERIALS AND METHOD**

#### **3.1 Work piece Materials**

#### **3.2 Steel Sample**

API 5L X42 was the specimen chosen for this investigation. The API 5L X42 steel pipe segment used for this research work was obtained from Pipeline and Product Marketing Company (PPMC) Port Harcourt, Nigeria.

#### **3.3 Soil Sample**

Four different states were chosen and soil collected from each state. All soil samples were taken from the depth of at least one (1) meter from the ground level. All of which were collected from four different sites along the Niger Delta region of Nigeria. The Niger Delta region is located at an elevation of 96 meters above sea level with latitude of 4° 49' 60"N and within longitude of 6° 0' 0" E. The soil samples were taken to the laboratory for analysis in an air tight polyvinyl bag less than 24 hours after collection from actual site.

#### **3.4 Specimen preparation of steel sample**

The steel pipe segment was sectioned (cut) into coupons of 72mm × 35mm × 10mm using a hacksaw. The cutting process was chosen so as not to alter the microstructure of the sample. To prevent inconsistent coating protection which may lead to bias result, the coatings of the samples were removed in a bid to allowing the coupons corrode under worst case scenario. As such, the samples were thoroughly cleaned before installation to avoid any contamination or any possible entities that could affect the corrosion process. The procedures of the preparation and cleaning process referred to ASTM G01- 03 (American Society for Testing and Material, 2003). A sample was subjected to chemical analysis using the metal analyzer. This was

done by exposing the well-polished surface of the sample to light emission from the spectrometer. The elements contained and their proportions in the sample were revealed on the digital processor attached to the spectrometer. The results as shown in table 3.1 below

Table 3.1: Chemical composition of API 5L X42 carbon steel (wt %).

C	Mn	P	S	Si
0.234	1.28	0.028	0.0215	0.4375

The close up view of coupon blank used for the investigation is shown below (Figure 3.1).



Fig. 3.1 Coupon blank freshly cut.

### 3.5 Specimen preparation of soil sample

The procedures followed in preparing the soil medium are referred to ASTM G162-99 (American Society for Testing and Material, 2010). Since the soil samples were collected from four different sites along the Niger Delta region of Nigeria, the soils were first packaged in polyvinyl bags and transferred from its actual site to a laboratory for determination of its chemical properties. The results are shown below

Table 3.2: Chemical analysis of experimental soils.

Parameters	Abia State	Bayelsa State	Delta State	Rivers State
pH	5.6	5.65	5.71	5.64
Redox Potential [mV]	147.8	142.8	140.5	148.6
Temperature [°C]	29.30	28.90	29.20	28.80
Soil Resistivity [ $\Omega \cdot cm$ ]	7013.77	6878.89	6973.50	6984.88
Chloride [mg/kg]	36.23	41.10	28.33	36.60
Sulphate [mg/kg]	11.10	12.45	9.87	13.99

Table 3.3 Mechanical and Physical analysis of experimental soil

States	% Sand	% Silt	% Clay	% moisture	% porosity	Permeability [cm/sec]
Abia	61.5	23.9	14.6	10.26	68	1.7
Bayelsa	73.1	15.2	11.7	21.05	58	0.9
Delta	71.2	17.6	11.2	11.27	65	1.5
Rivers	58.8	21.3	19.9	10.41	70	1.2

### 3.6 Soil Chemical Analysis

#### 3.6.1 Test Procedure: Soil Ph (pH (APHA 4500 H<sup>+</sup>))

Measurement was carried out in 1:1 soil to water suspension by means of a Win Lab pH meter (WinLab 192363, Germany), which was calibrated in the laboratory. Calibration was checked by measuring standard buffer solutions.

#### 3.7 Test Procedure: Soil Resistivity

Electrical Conductivity was carried out based on APHA-2540-C standards. Measurement was carried out in 1:1 soil to water suspension by means of a Win Lab conductivity meter (WinLab 200363, Germany), which was calibrated in the laboratory. Calibration was checked by measuring standard Conductivity reference solutions. Soil resistivity being reciprocal of conductivity was however computed using

$$ER = \frac{1}{EC} \quad (3.1)$$

Where

ER = Electrical resistivity

EC = Electrical conductivity

### 3.8 Burial of Samples

The coupons were totally buried inside plastic containers containing the respective soils gotten from different states in a laboratory and closely monitored. A total of 4 steel coupons were buried and allowed to corrode naturally for a period of seven days (168 hours).

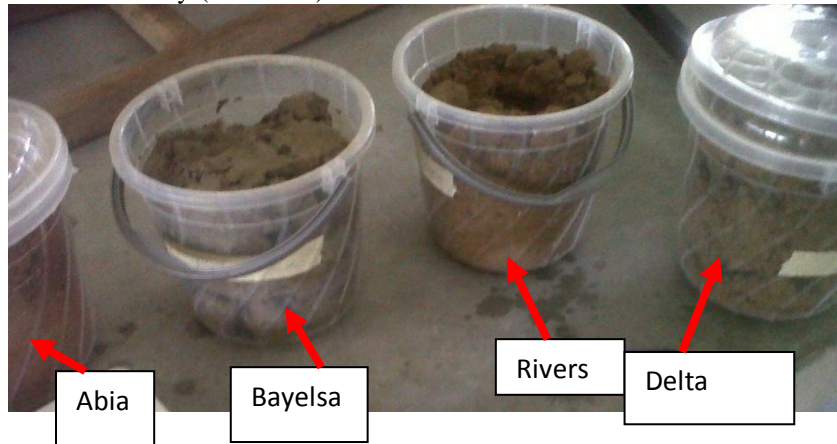


Fig. 3.2 Soil samples in containers ready for coupon burial



Fig. 3.3a Burial of coupon in Delta and Rivers State soils



Fig. 3.4b Coupon burial into Bayelsa and Abia state soil samples

### 3.9 Retrieval of Coupons

Coupon retrieval was carried out periodically every seven days. As such, in order to get a time-function data of metal loss, every single sample was assumed uniform in terms of strength, thickness and corrosion resistance.



Fig. 3.5 Retrieval of one of the coupons from soil

### 3.9.1 Weight loss measurement

To remove accumulated impurities and corrosion products from the coupons, two cleaning techniques were employed, which included mechanical cleaning and chemical cleaning (refer to Figure 3.6).



Fig. 3.6 Washing the coupons

The mechanical cleaning was carried out to remove the soil particles on the surface of samples using a soft brush. After washing, all the coupons were neutralized by 5% sodium carbonate and again washed with water. After neutralization, the coupons were soaked in Acetone for 5 minutes and then allowed to dry properly in sun. The weight of the sample prior ( $W_1$ ) and after being exposed to soil environment ( $W_2$ ) were recorded using an electronic weighing scale to determine the corrosion rate. Yahaya and others (2011) asserted that the difference in weight of the sample is most often used as a measure of corrosion or the basis for calculation of the corrosion rate.

$$W = W_1 - W_2 \quad (3.2)$$

where,

W = weight loss

$W_1$  = initial weight

$W_2$  = final weight after exposure to soil with time

### 3.9.2 Corrosion Rate Determination

The surface area of each coupon was calculated using the following equation:

$$Surface\ Area(A) = 2 \times [(L \times B) + (B \times T) + (L \times T)] \dots \dots \dots (3.3)$$

where,

L = Length of the coupon.

B = Width of the coupon.

T = Thickness of the coupon.

D = Diameter of hole in coupon

The weight loss of the coupons which were used to compute the corrosion rates of the coupons was measured using the KERRO BLG 2000 electronic scale having a precision of upto 0.01gm. Hence the corrosion rate was computed using the formula:

$$Corrosion\ rate\ (mmpy) = \frac{87.6 \times Weight\ loss}{Area \times time \times Density} \quad (3.4)$$

Where:

W = weight loss in milligrams

A= area of coupon in  $cm^2$

T = time of exposure of coupon in hours

$\rho$  = metal density in  $g/cm^3$

#### IV. RESULT AND DISCUSSION

##### 4.1 Weight loss of samples

In order to see the influence of soils from different locations on the coupons buried, the initial weight of the coupons were recorded and with time the weight differences were checked. The weight loss plotted as shown in Figure 4.1.

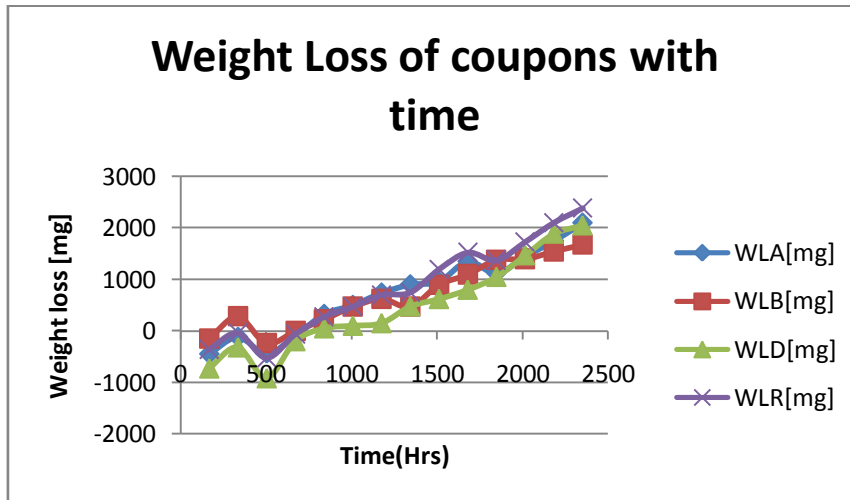


Fig. 4.1: Weight loss against time.

##### 4.2 Corrosion Growth rate

Corrosion growth rate has always been a function of time. Upon inspection based experimental data recorded, it seemed evident that the corrosion rate of coupons increased with time after the initial stage.

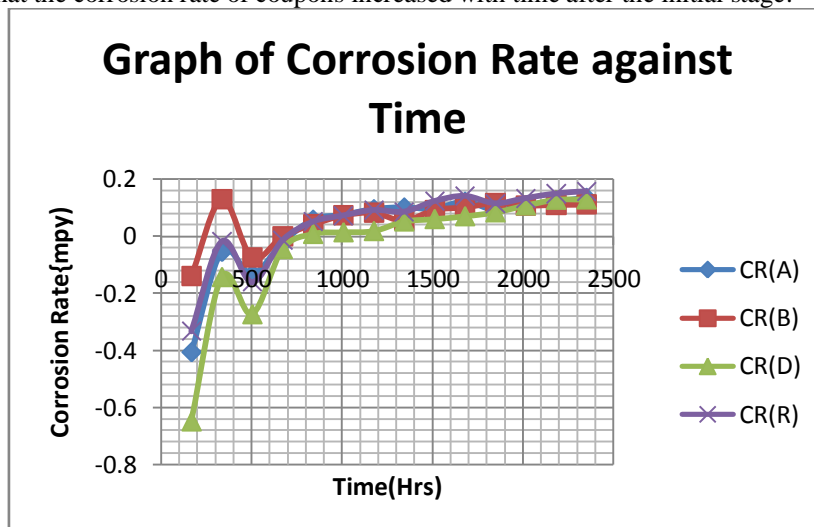


Fig. 4.3 Graph of corrosion rate against time

##### 4.3 Analysis of Variance (ANOVA)

The experimental results were analyzed with analysis of variance (ANOVA), which is used for identifying the factors significantly affecting the corrosion rates of the coupons. The results of the ANOVA with the soil resistivity and pH are shown in Tables 4.1 and 4.2 respectively. This analysis was carried out for significance level of  $\alpha = 0.05$  i.e. for a confidence level of 95%. The sources with a P-value less than 0.05 are considered to have a statistically significant contribution to corrosion behaviour of the coupons

##### 4.3.1 Analysis of Variance for Resistivity

Table 4.1: Analysis of Variance (ANOVA) for Resistivity.

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
-0.018	27	1.811045	0.067076	0.005244
6114.375508	27	161801	5992.63	69296.16

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	484795868	1	4.85E+08	13992	6.667E-65	4.026631
Within Groups	1801700.25	52	34648.08			
Total	486597568	53				

Table 4.2: Regression analysis.

SUMMARY OUTPUT

*Regression Statistics*

Multiple R	0.843429448
R Square	0.711373235
Adjusted R Square	0.700272205
Standard Error	0.039887668
Observations	28

ANOVA

	<i>Df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	0.101956	0.101956	64.08174	1.74787E-08
Residual	26	0.041367	0.001591		
Total	27	0.143322			

The following are deductions are made from the ANOVA and Regression table

1. The Model F-value of 64.082 implies the model is significant. There is only a 0.000000174% chance that a “Model F-Value” this large could occur as a result of resistivity.  $F(64.08) > \text{Sig. } F(1.748 \times 10^8) < 0.05 = \alpha$
2.  $F(64.082) > F_{crit}(4.027)$  as such null hypothesis is rejected. Since  $P - \text{value} = 6.667 \times 10^{-65} < 0.05 = \alpha$  hence it is significantly a good fit. In terms of resistivity as a parameter which affects corrosion rate.
3. The output R-square value (0.7114) indicates the accuracy of the model and the coefficient of determination (Adj) R-square (0.7003) for the model is close which indicates compatibility/correlation of experimental data.

4.3.2 Analysis of Variance (ANOVA) for pH

Table 4.3: Regression Analysis result for pH.

SUMMARY

OUTPUT

pH

*Regression Statistics*

Multiple R	0.58241252
R Square	0.339204344
Adjusted R Square	0.313789126
Standard Error	0.060353705
Observations	28

ANOVA					
	<i>Df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	0.048615577	0.0486156	13.34651	0.001146843
Residual	26	0.094706813	0.0036426		
Total	27	0.14332239			

Table 4.4: Analysis of Variance (ANOVA) for pH.  
Anova: Single Factor for pH

SUMMARY				
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
-0.018	27	1.811045	0.067076	0.005244
5.54	27	161.23	5.971481	0.018505

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	470.6371	1	470.6371	39633.64	1.24E-76	4.026631
Within Groups	0.617484	52	0.011875			
Total	471.2546	53				

The following are deductions are made from the ANOVA and Regression table

1. The Model F-value of 13.347 implies the model is significant. There is only a 0.00001147% chance of getting a correlation of ( $R^2 = 0.3392$ ) for pH as a parameter only.
2. Since  $P - value = 0.0011468 < 0.05 = \alpha$  as such null hypothesis is rejected. Hence it is significantly a good fit. In terms of pH as a parameter which affects corrosion rate.
3. The output R-square value (0.3392) indicates the accuracy of the model and the coefficient of determination (Adj) R-square (0.3138) for the model is quite close although low.

4.3.3 Regression Equation and Analysis of Variance (ANOVA) for experimental data

Table 4.5: Regression Analysis Result of Experiment.

<i>Regression Statistics</i>	
Multiple R	0.90162
R Square	0.81292
Adjusted R Square	0.79796
Standard Error	0.03274
Observations	28

ANOVA						
	<i>Df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	2	0.11651	0.0582	54.319	7.945E-10	
Residual	25	0.02681	0.0010			
Total	27	0.14332				

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>
Intercept	0.356389	0.33931	1.0503	0.30361	-0.34243	1.05521	-0.34243
RES	-0.000205	2.5786E-05	-7.957	2.59E-08	-0.000258	-0.00015	-0.000258
PH	0.157498	0.04275	3.684	0.0011	0.0694482	0.245547	0.0694482



Table 4.6: Anova And Regression Analysis To Check For Correlation Between Resistivity and Corrosion Rate.

Anova: Single Factor  
SUMMARY

Groups	Count	Sum	Average	Variance
CR	28	1.793045	0.064037	0.005308
R	28	167915.4	5996.978	67258.99

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.03E+08	1	5.03E+08	14971.43	1.08E-67	4.019541
Within Groups	1815993	54	33629.5			
Total	5.05E+08	55				

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.843429
R Square	0.711373
Adjusted R Square	0.700272
Standard Error	0.039888
Observations	28

ANOVA

	Df	SS	MS	F	Significance F
Regression	1	0.101956	0.101956	64.08174	1.75E-08
Residual	26	0.041367	0.001591		
Total	27	0.143322			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.484995	0.177666	8.358334	7.7E-09	1.119797	1.850193
RESISTIVITY	-0.00024	2.96E-05	-8.00511	1.75E-08	-0.0003	-0.00018

The relationship between the two properties studied (pH and Resistivity) and corrosion rate was modelled by multiple linear regression (Table 4.5). The final regression model in terms of coded parameters for corrosion rate:

$$CR_{model} = 0.3564 - 0.00021RES + 0.1574PH \quad (R = 0.9016) \quad (4.1)$$

where

RES = soil resistivity

PH = soil pH

The following deductions were made;

1.  $R^2 = 0.8129$ ; hence 81.29% of the variation in the corrosion rate is explained by the regression model formulated above, which shows a significantly good fit. While Adjusted  $R^2 = 79.80\%$ . This shows how correlated the relationships are.
2. The Standard Error ( $S_E = 0.0327$ ) which shows the deviation of experimental from predicted seemed very low, showing how good the model is.
3. The  $P - value$  for RES ( $2.59 \times 10^{-8}$ ) and for pH (0.00111)  $< 0.05$  shows again that there is a relationship between both parameters as against corrosion rate.
4. From the regression model above, the pH coefficient is greater than that of the resistivity, which means that soil pH has a greater influence on the rate of corrosion reaction for coupons buried underground.

#### 4.3.4 Goodness of Fit for corrosion rate as influenced by both parameters

To test whether the discrepancies between the experimental and predicted values of corrosion rate, we use the statistic for test of goodness of fit using the equation below:

$$\chi^2 = \sum_{i=1}^k \frac{(E_i - P_i)^2}{E_i} \quad (4.2)$$

Table 4.6 showed that  $\chi^2 = 1.0972$  for corrosion rate for 27 degrees of freedom whereas degrees of freedom used is given by:

$$(rows - 1) \times (col - 1) = (28 - 1) \times (2 - 1) = 27$$

Therefore the analysis of data does suggest perception is correct with 95 % confidence level. Otherwise, there is reason to believe that the program does give correct output as shown in Table 4.7.

Table 4.7: Statistic for Test of Goodness of fit.

Observation	Statistic for Test of Goodness of Fit		
	Experimental CR	Predicted CR	$\frac{(Exp - Pre)^2}{Pre}$
1	-0.018	-0.02558006	-0.00225
2	-0.014	0.007567643	0.061467
3	0.073	0.029167382	0.065871
4	0.086	0.07501557	0.001608
5	0.141	0.09462737	0.022725
6	0.133211	0.143206435	0.000698
7	0.157336	0.187353985	0.00481
8	0.1294	0.031160648	0.309717
9	0	0.040792761	0.040793
10	0.0731	0.051729332	0.008829
11	0.0549	0.07141824	0.00382
12	0.1016	0.09475486	0.000494
13	0.107794	0.104513599	0.000103
14	0.110874	0.116796196	0.0003
15	-0.142	-0.11231227	-0.00785
16	-0.044	-0.03519792	-0.0022
17	0.0148	0.014253608	2.09E-05
18	0.0526	0.023737458	0.035094
19	0.0709	0.07973124	0.000978
20	0.1086	0.110817272	4.44E-05
21	0.1298	0.131064449	1.22E-05
22	-0.0541	0.010422001	0.399452
23	-0.0226	0.007502196	0.120784
24	0.07518	0.042970274	0.024144
25	0.1015	0.117529349	0.002186
26	0.1218	0.106078952	0.00233
27	0.10902	0.119713709	0.000955
28	0.13533	0.154210713	0.002312
			1.097253

To verify the goodness of the predicted model, the observed experimental values and their predictive values of the corrosion rate is given in the Table 4.6. Table 4.6 also shows the prediction error of the corrosion rate. It has been seen that the maximum and minimum error for corrosion rate is 6.191 and -3.152, which is satisfactory. Graphical comparison of actual and predicted values of surface roughness and material removal rate is shown in Figure 4.4.

Table 4.8: Comparison between Experimental and predicted values of Corrosion rate.

COMPARISM BETWEEN EXPERIMENTAL AND PREDICTED VALUES OF CORROSION RATE				
Observation	Predicted CR	Residuals	Experimental CR	ERROR
1	-0.0256	0.0076	-0.018	0.2963

2	0.0076	-0.0216	-0.014	2.85
3	0.0292	0.0438	0.073	-1.5028
4	0.075	0.011	0.086	-0.1464
5	0.0946	0.0464	0.141	-0.4901
6	0.1432	-0.01	0.1332	0.0698
7	0.1874	-0.03	0.1573	0.1602
8	0.0312	0.0982	0.1294	-3.1527
9	0.0408	-0.0408	0	1
10	0.0517	0.0214	0.0731	-0.4131
11	0.0714	-0.0165	0.0549	0.2313
12	0.0948	0.0068	0.1016	-0.0722
13	0.1045	0.0033	0.1078	-0.0314
14	0.1168	-0.0059	0.1109	0.0507
15	-0.1123	-0.0297	-0.142	-0.2643
16	-0.0352	-0.0088	-0.044	-0.2501
17	0.0143	0.0005	0.0148	-0.0383
18	0.0237	0.0289	0.0526	-1.2159
19	0.0797	-0.0088	0.0709	0.1108
20	0.1108	-0.0022	0.1086	0.02
21	0.1311	-0.0013	0.1298	0.0096
22	0.0104	-0.0645	-0.054	6.1909
23	0.0075	-0.0301	-0.023	4.0125
24	0.043	0.0322	0.0752	-0.7496
25	0.1175	-0.016	0.1015	0.1364
26	0.1061	0.0157	0.1218	-0.1482
27	0.1197	-0.0107	0.109	0.0893
28	0.1542	-0.0189	0.1353	0.1224

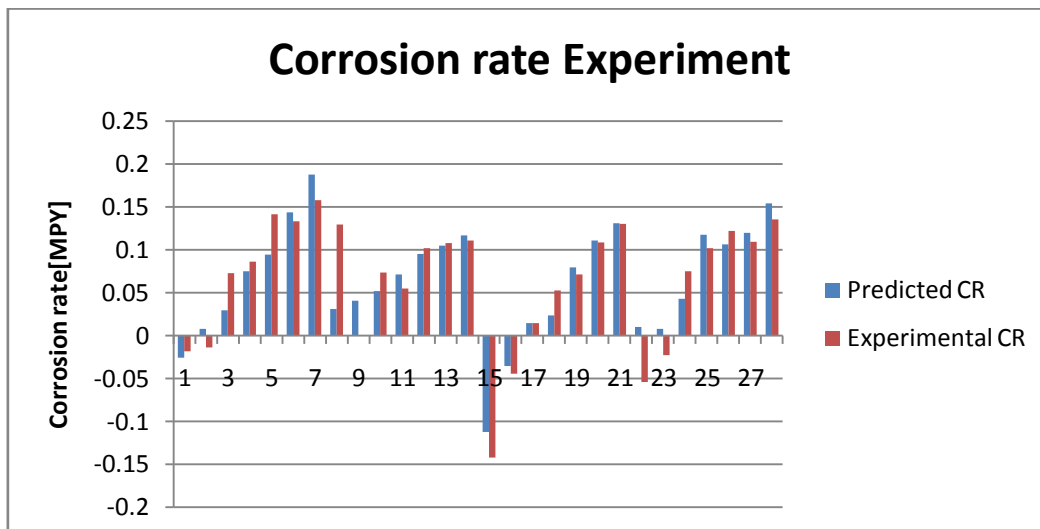


Fig. 4.4: Comparison between Actual and Predicted Values of Surface Roughness.

### V. DISCUSSION OF FINDING AND CONCLUSION

The aim of the study was to determine a relationship between soil pH and soil resistivity upon corrosion growth rate of carbon steel and develop prediction model for corrosion growth rate using multiple regression analysis. Based on the results of these experimental investigations, the following conclusions can be drawn:

- Soil resistivity was found to have greater influence than soil pH towards the acceleration of corrosion reaction in most soil samples examined, if not all, due to distinct pattern of relationship between variations of averaged corrosion rates and soil properties.
- Using Analysis of Variance (ANOVA) the individual factor effects are found out and concluded that the effect of resistivity is one parameter with more effect when compared to pH.

- The Multiple Regression Analysis method is used to develop the corrosion rate prediction models using the predictors such as soil pH and resistivity for different soil samples. A multiple regression model is developed to suit all the soil types from different locations. These models show good agreement with experimental results.

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