Predictive Model for Corrosion Inhibition of Mild Steel in HCl by Crushed Leaves of Clerodendrum Splendens

Agha Inya Ndukwe[1] and C. N. Anyakwo[2]

1. Department of Metallurgical Engineering Technology, Akanu Ibiam Federal Polytechnic Unwana, P.M.B. 1007, Afikpo, Nigeria.

2. Department of Materials and Metallurgical Engineering, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria.

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Abstract - *The corrosion inhibition of mild steel in 0.7M, 1.2M and 2.2M HCl by thoroughly crushed leaves of Clerodendrum Splendens has been studied using the weight-loss technique. The corrosion rate curves were observed to continuously decrease with time whilst the inhibition efficiency improved as the experimentation progressed. For the entire study environment, the highest inhibition efficiency of 70.70% was achieved when the thoroughly crushed leaves of Clerodendrum Splendens were added at 45g per litre of 1.2M HCl while the corrosion rate reduced from 0.6738mgcm^{-2}h^{-1} to 0.2465mgcm^{-2}h^{-1}. The predictive corrosion rate model was developed using multiple regression and artificial neural network. The prediction of the experimental corrosion rate by the artificial neural network revealed the importance of independent variables; (time (h), concentration of acid (M) and quantity of crushed leaves (g)) in the prediction of the dependent variable (Corrosion rate, CR (mgcm^{-2}h^{-1}). The addition of the crushed leaves of Clerodendrum Splendens to the hydrochloric acid induced corrosion of mild steel indicates that the time of exposure vastly influenced the prediction of the corrosion rate by 47.7%, followed by the quantity of pounded leaves, 26.6% and finally the concentration of acid, 25.7%. Predictions by the artificial neural network gave a minimal error and were closer to the experimental corrosion rate values in comparison with the predictions by multiple regression. The protective film formed on the mild steel surface was analyzed by FTIR spectroscopy and Scanning electron microscopy (SEM). The FTIR analysis indicates that the adsorbed constituents of the crushed fresh leaves of Clerodendrum Splendens on the surface of mild steel, immersed at 30g per litre of 0.7M HCl for eight hours is associated with the stretching vibrations of O–H, C≡C and C=C bonds. The SEM image shows that corrosion was localized on the surface of mild steel when immersed in the uninhibited solution of 0.7M HCl but the addition of Clerodendrum Splenden's pounded fresh leaves at 30g per litre of 0.7M clearly inhibited the mild steel from corrosion. The phytochemical analysis of the leaves of Clerodendrum Splendens reveals the presence of alkanoid, tannin, saponin, phytate, flavonoid and phenol.*

Key Words*: *Inhibition efficiency, Hydrochloric acid, Corrosion rate, Clerodendrum Splendens, Artificial eural network, Multiple regression.

1. INTRODUCTION

Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with its environment **[1]**. When a metal interacts with the environment, the tendency of the metal to revert to its original state where it was in combination with other elements is imminent. The overall outcome of corrosion as acknowledged by **[2]** is that a metal undergoes an electrochemical reaction as a result of its surrounding to form a compound similar to the one from which it was won. The destructive effect of a metal has huge financial toll running into billions. For instance, the total annual corrosion cost in the US rose from $276 billion in 1998 to above $1 trillion in the middle of 2013 and is now estimated at $1.1 trillion for 2016 **[3].**

The addition of an inhibitor is one of the techniques used to prevent corrosion. Inhibitors are substances that prevent the corrosion of metals and alloys when added in minute quantity to the corrodent. This may be achieved by lowering anodic or cathodic reaction rates or both simultaneously **[2].** One of such substances often used as an inhibitor is chromate which is toxic and carcinogenic **[1].** The toxicity effect of the known synthesized inhibitors has driven contemporary studies towards the use of plant extracts as anti-corrosion agents, because they are mostly harmless.

Green inhibitors like natural products from plant extracts and substances from other renewable sources are of the interest of researchers who are desirous of green chemistry or eco-friendly technologies **[4].** This research examines the leaves of Clerodendrum Splendens as a veritable candidate for the inhibition of mild steel in hydrochloric acid. Clerodendrum Splendens (Verbenaceae) is a woody or semi-woody evergreen vine or running shrub to 12ft (3.7m) long that climbs by twining. The leaves are oval to *7in (18cm)* long and arranged in opposite pairs **[5].**

Inhibitors have always been considered to be the first line of defence against corrosion in various industries. A great number of scientific studies have been devoted to the subject of corrosion inhibitors but according to **[6]**; rules, equations and theories to guide inhibitor development or use are very limited. The rate at which corrosion takes place is obtained thus:

$$\text{Corrosion rate, } CR = \frac{W_2 - W_1}{A \times t} \quad \ldots\ldots\ldots \quad (1)$$

Where,

$W_2 - W_1$ = Weight loss.

A = Exposed area.

t = Exposure time.

The efficiency of an inhibitor can be expressed by a measure of this improvement:

$$\text{I.E } (\%) = \frac{CR_2 - CR_1}{CR_2} \times 100 \quad \ldots. \quad (2)$$

Where,

CR2 = Corrosion rate of the uninhibited system.

CR1 = Corrosion rate of the inhibited system.

In essence, addition of excessive amount of inhibitor is unnecessary not only on the grounds of economy and waste disposal but simply because a limiting corrosion rate is achieved at high inhibitor concentrations **[2].**

2.0 Experimental Details

2.1 Materials and equipment

The various items that led to the successful conduct of this research were: Mild steel coupons, Metre rule, Centre punch, Scriber, Coarse and fine emery papers (grades 200 and 800), Razor blade, Masking tape, Hand file, Nylon hand gloves, Plastic jerry cans, Laboratory beakers, Measuring cylinder, Plastic buckets, Distilled water, HCl, Acetone, Cotton wool and Manual blender.

The Ohaus electronic weighing balance, which gave results to the accuracy of 0.0001g, was used to weigh the mild steel coupons before and after exposure to different study-environments in order to obtain the exact weight difference. Hand-held drilling and foot-shear cutting machines were also used in fabricating the mild steel coupons.

2.2 Preparation of plant-leaf extact

The plant leaves were acquired within the University (FUTO) environment and pounded thoroughly with a manual bender before addition to different study environments at 15g per litre, 30g per litre and 45g per litre of different hydrochloric acid concentrations.

2.3 Fabrication of steel coupons

Mechanically cut coupons of *40mm x 40mm x 1.5mm* dimensions were prepared from a sheet metal with the following composition (wt %) C=0.20%, Zn=0.75%, Ti=0.28, Mn=0.23%, S=0.04%, P=0.035% and Fe balance. Prior to the experiment, the coupons were abraded using coarse and fine emery papers (grades 200-800), washed with distilled water and acetone and finally dried. The initial weight of each specimen was noted before immersion using the Ohaus electronic weighing balance.

2.4 Weight-loss measurement

Solutions of various concentrations of *0.7M, 1.2M and 2.2M* HCl were prepared for the experiment with distilled water using dilution formula. Experiments were conducted under total immersion in aerated condition using *2500ml* capacity bowl containing *1000ml (1litre)* test solution. The plant leaves were thoroughly crushed and added at 15g per litre, 30g per litre and 45g per litre of *0.7M, 1.2M and 2.2M* HCl. During the period of experimentation the coupons were immersed in various hydrochloric acid concentrations to which different quantities of the pounded leaves of Clerodendrum Splendens had been added. A similar set-up which had no inhibitor was prepared to provide comparison for the observed result. Each experimental set up lasted for eight hours.

The moisture content of the leaves of Clerodendrum Splendens as at the time of the experiment was 70.17%. Meanwhile, another round of experimentation was carried out by varying the temperature from 293, 318, and 338 to 358K. The initial and final weights of the steel coupons were measured and recorded, including the area of exposure.

2.5 Model development

2.5.1 Multiple regression

In multiple regression, the variable whose value is to be predicted is known as the dependent variable and the ones whose known values are used for prediction are known as independent variables. In general, the multiple regression of Y on $X_1, X_2, ..., X_k$ is given by **[7]:**

$$Y = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k \quad .... (3)$$

Where,
Y = the dependent variable.
b_o = *intercept on the vertical axis.*
b_1 = *the change in Y for each 1 increment change in* X_1.
b_2 = *the change in Y for each 1 increment change in* X_2.
b_k = *the change in Y for each 1 increment change in* X_k.
X_1 = *an X score on the first independent variable for which you are trying to predict a value of Y.*
X_2 = *an X score on your second independent variable for which you are trying to predict a value of Y.*

2.5.2 Artificial neural network

An artificial neural network refers to a computational model that is based on the structure and functions of biological neural networks. One of the most advantages of ANN is its ability to learn from observing data sets **[11].** In this way, ANN is used as a random function approximation tool.

The basic building block of artificial neural network (ANN) is the neuron. A neuron is a processing unit which has some (usually more than one) inputs and only one output as shown in Figure 1. First each input x_i is weighted by a factor w_i and the whole sum of inputs is calculated thus **[8]**:

$$Total\ input, a = \left(\sum_{all\ inputs} w_i x_i \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Then an activation function f, is applied to the result a. The neuronal output is taken to be *f (a)*:

$$\text{Output} = Activation\ function \left(\sum_{all\ inputs} w_i x_i \right) = f(a) \ldots\ldots\ldots \quad (5)$$

Where,

x_i = *input.*
w_i = *weight.*

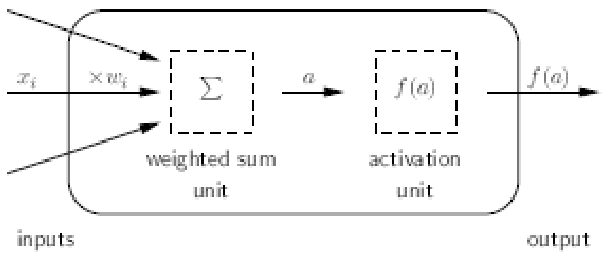


Figure 1: The typical artificial neuron **[8].**

This function (f) is called the activation or signal function. The most used function is the logistic signal function:

$$f(a) = \frac{1}{1 + e^{-ca}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

3.0 RESULTS AND DISCUSSION

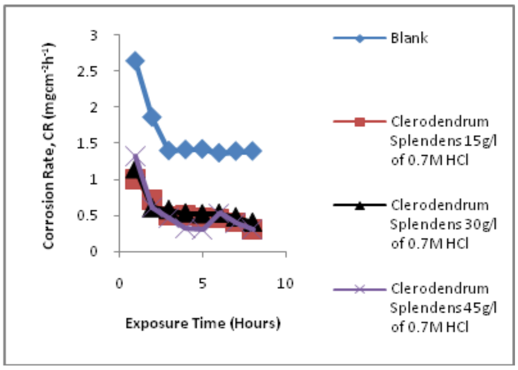
3.1 Effect of addition of thoroughly pounded fresh leaves of Clerodendrum Splendens on the corrosion of mild steel coupons immersed in hydrochloric acid medium

The addition of the crushed leaves of Clerodendrum Splendens at 15g per litre of 0.7M, 1.2M and 2.2M HCl gave the following average corrosion rate, CR and inhibition efficiency, I.E in the order CR (I.E) as presented in Table 1: 0.5468$mgcm^{-2}h^{-1}$ (66.74%) in 0.7M HCl, 0.8434$mgcm^{-2}h^{-1}$ (34.26%) in 1.2M HCl and 1.6714$mgcm^{-2}h^{-1}$ (31.63%) in 2.2M HCl. As the addition of the crushed leaves was increased to 30g per litre of various acid concentrations, the corresponding average corrosion rate and inhibition efficiency were: 0.6054$mgcm^{-2}h^{-1}$ (64.96%) in 0.7M HCl, 0.6566$mgcm^{-2}h^{-1}$ (51.05%) in 1.2M HCl and 1.4579$mgcm^{-2}h^{-1}$ (40.40%) in 2.2M HCl. Further addition of the pounded leaves at 45g per litre of different acid solutions gave the following average corrosion rate and inhibition efficiency: 0.5383 $mgcm^{-2}h^{-1}$ (68.41%) in 0.7M HCl; 0.3762$mgcm^{-2}h^{-1}$ (70.70%) in 1.2M HCl and 1.3648$mgcm^{-2}h^{-1}$ (39.38%) in 2.2M HCl. It can be seen that the addition of the thoroughly crushed leaves of the plant reduced the corrosion of mild steel and the corrosion rate increased with increase in hydrochloric acid concentration whilst the inhibition efficiency improved as the experimentation progressed. This outcome highlights the importance of time in the inhibition process.

Figure 2 shows the corrosion rate–time curves for the mild steel coupons immersed in 0.7M, 1.2M and 2.2M HCl with and without the crushed leaves of Clerodendrum Splendens. The corrosion rate curves decreased progressively as the exposure time increased.

Table 1: Effect of addition of thoroughly crushed leaves of Clerodendrum Splendens on the corrosion of mild steel coupons immersed in hydrochloric acid solution

t	0.7M HCl		1.2M HCl		2.2M HCl	
	CR ($mgcm^{-2}h^{-1}$)	I.E (%)	CR ($mgcm^{-2}h^{-1}$)	I.E (%)	CR ($mgcm^{-2}h^{-1}$)	I.E (%)
Addition of crushed leaves of Clerodendrum Splendens at 15g per litre of HCl						
1	1.0078	61.95	1.3999	38.76	4.5220	24.16
2	0.7232	61.21	0.9947	36.57	2.3278	34.84
3	0.4957	64.47	0.7445	32.98	1.6351	32.90
4	0.5061	64.20	0.7326	37.67	1.3258	30.41
5	0.4728	66.74	0.8632	27.08	1.0990	29.92
6	0.4579	66.54	0.7788	25.62	0.9425	29.99
7	0.4070	70.72	0.6954	33.44	0.7481	37.74
8	0.3050	78.11	0.5384	41.96	0.7711	33.06
Av.	**0.5468**	**66.74**	**0.8434**	**34.26**	**1.6714**	**31.63**
Addition of crushed leaves of Clerodendrum Splendens at 30g per litre of HCl						
1	1.1588	56.25	1.4434	36.85	3.8018	36.24
2	0.6114	67.21	0.8074	48.52	2.0025	43.94
3	0.5867	58.06	0.6177	41.96	1.5596	36.00
4	0.5380	61.94	0.6237	46.93	1.3454	29.38
5	0.5251	63.06	0.5820	50.84	0.9416	39.96
6	0.5334	61.02	0.4957	52.66	0.7997	40.60
7	0.4829	65.32	0.3576	65.77	0.6522	45.72
8	0.4070	70.79	0.3256	64.90	0.5602	51.37
Av.	**0.6054**	**64.96**	**0.6566**	**51.05**	**1.4579**	**40.40**
Addition of crushed leaves of Clerodendrum Splendens at 45g per litre of HCl						
1	1.3215	50.11	0.6738	70.52	3.0536	48.79
2	0.6186	66.82	0.4016	74.39	1.9009	46.79
3	0.4724	66.23	0.3427	69.15	1.2815	47.41
4	0.3318	76.53	0.3601	69.36	1.1429	40.01
5	0.3102	78.18	0.2626	77.82	1.0938	30.26
6	0.5344	60.95	0.4715	54.97	0.8940	33.59
7	0.4012	71.19	0.2465	76.40	0.8003	33.40
8	0.3166	77.27	0.2509	72.95	0.7515	34.75
Av.	**0.5383**	**68.41**	**0.3762**	**70.70**	**1.3648**	**39.38**



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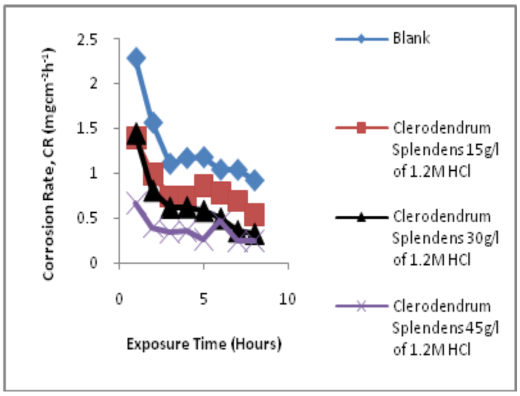

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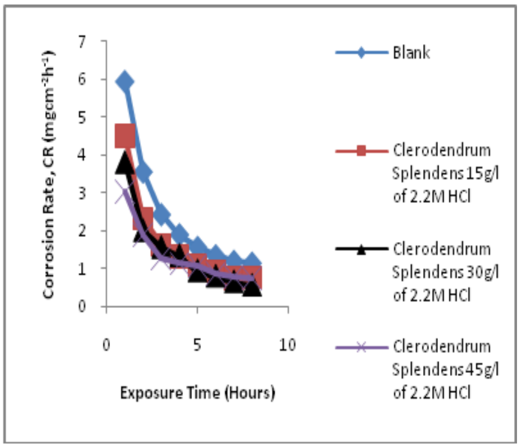
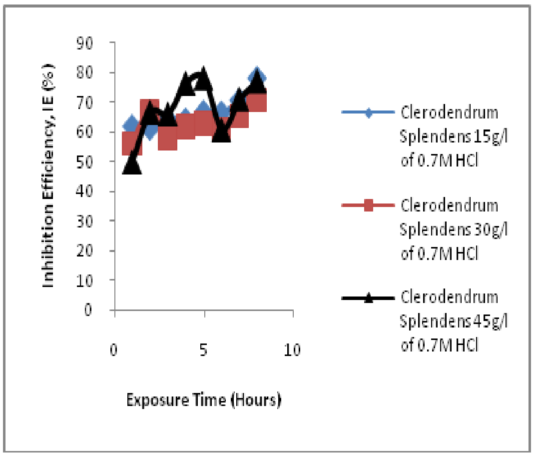


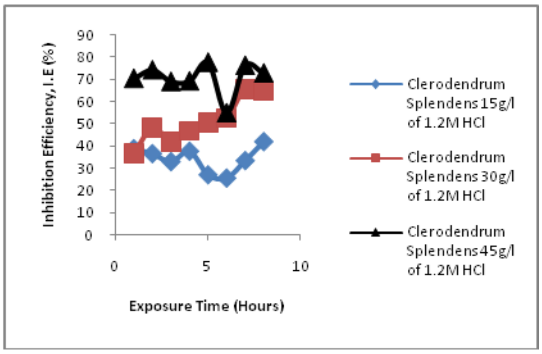
(c)

Figure 2: Effect of addition of thoroughly crushed fresh leaves of Clerodendrum Splendens on corrosion of mild steel coupons immersed at:
(a) 15g/l, 30g/l and 45g/l of 0.7M HCl
(b) 15g/l, 30g/l and 45g/l of 1.2M HCl
(c) 15g/l, 30g/l and 45g/l of 2.2M HCl



(a)

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 02 |Feb -2017 www.irjet.net p-ISSN: 2395-0072



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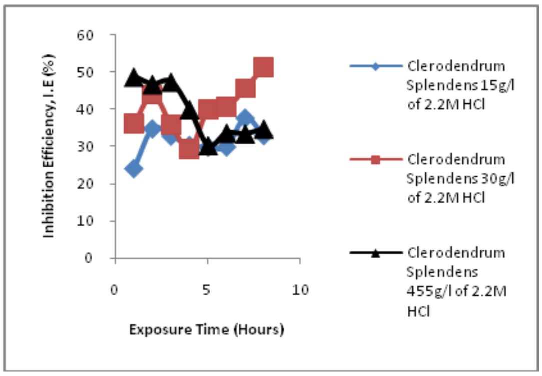


(c)

Figure 3: Clerodendrum Splendens's corrosion inhibition efficiency for mild steel coupons immersed at:
(a) 15g/l, 30g/l and 45g/l of 0.7M HCl
(b) 15g/l, 30g/l and 45g/l of 1.2M HCl
(c) 15g/l, 30g/l and 45g/l of 2.2M HCl

The corrosion rate of mild steel, in all the studied environments is lower in the presence of the crushed leaves of Clerodendrum Splendens than in the blank acid solution. This development can be attributed to the palliating effect of the plant-leaf extract on the corrosion rate of mild steel in acidic medium.

The inhibition efficiency–time curves for mild steel coupons occasioned by the addition of the crushed leaves of Clerodendrum Splendens at 15g per litre, 30g per litre and 45g per litre of 0.7M, 1.2M and 2.2M HCl corrodents are displayed in Figure 3. The inhibition efficiency was observed to improve with time. This indicates that the inhibitive constituents in the plant extract need some considerable period of time, to adhere to the surface of the mild steel to prevent further corrosive attack on the steel as confirmed by the Langmuir adsorption isotherm (Figure 7). The maximum inhibition efficiency of 70.70% was achieved when the crushed leaves of Clerodendrum Splendens was added at 45g per litre of 1.2M HCl.

3.2 Prediction of corrosion inhibition of mild steel in hydrochloric acid medium by thoroughly pounded leaves of Clerodendrum Splendens using multiple regression and artificial neural network

Multiple regression and artificial neural network were used to predict the corrosion rates of mild steel coupons with and without the addition of Clerodendrum Splendens's crushed leaves in hydrochloric acid solution. The predicted values are presented in Appendix 1.

Using multiple regression as illustrated in Table 2, the predictive equation for the addition of crushed leaves of Clerodendrum Splendens to the hydrochloric solution is stated thus:

$CR_{CS\ in\ HCl\ by\ MR}$ = 1.622 – 0.204(time) + 0.645(conc. of acid) – 0.021(quantity of crushed leaves) .... (7)

On the other hand, the prediction of the experimental corrosion rate by the artificial neural network revealed the importance of independent variables (time (h), concentration of acid (M) and quantity of crushed leaves (g)) in the prediction of the dependent variable (Corrosion rate, CR ($mgcm^{-2}h^{-1}$) for the addition of thoroughly pounded leaves of Clerodendrum Splendens to hydrochloric acid medium as presented in Table 3. The time of exposure vastly influenced the prediction of the corrosion rate by 47.7%, followed by the quantity of the plant's crushed leaves, 26.6% and finally the concentration of acid, 25.7%.

Table 2: Analysis for prediction of corrosion inhibition of mild steel by the crushed leaves of Clerodendrum Splendens in hydrochloric acid medium using multiple regression (MR)

	Model Coefficients			
	Constant	Time (h)	Conc. of Acid (M)	Quantity of Pounded Leaves (g)
HCl	1.622	-0.204	0.645	-0.021

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 02 |Feb -2017 www.irjet.net p-ISSN: 2395-0072

Table 3: Analysis for prediction of corrosion inhibition of mild steel in hydrochloric acid solution by thoroughly pounded leaves of Clerodendrum Splendens using artificial neural network (ANN)

Independent variable importance for the crushed leaves of Clerodendrum Splendens in hydrochloric acid

	Importance	Normalized Importance
Time	0.477	100.0%
Conc_of_HCl	0.257	53.8%
Quantity_of_Pounded leaves	0.266	55.8%

Parameter estimates for the crushed leaves of Clerodendrum Splendens in hydrochloric acid

Predictor		Predicted		
		Hidden Layer 1		Output Layer
		H(1:1)	H(1:2)	Exp_Corrosion_Rate
Input Layer	(Bias)	0.403	3.629	
	Time	-0.070	2.145	
	Conc_of_HCl	-0.437	-0.883	
	Quantity_of_Crushed_Leaves	1.426	0.010	
Hidden Layer 1	(Bias)			2.513
	H(1:1)			-1.916
	H(1:2)			-3.878

Table 4: Error analysis for the prediction of corrosion inhibition of mild steel by thoroughly pounded leaves of Clerodendrum Splendens in hydrochloric acid solution using multiple regression, MR and artificial neural network, ANN

Error	Prediction of CR by Multiple Regression, MR	Prediction of CR by Artificial Neural Network, ANN
Mean Absolute Error	0.402085521	0.221795833
Mean Squared Error	0.344539983	0.090694302

The mean absolute error (MAE) and mean squared error (MSE) were used to investigate how close the predicted value was to the actual value. The comparison of error results for the prediction of corrosion inhibition of mild steel by the leaves of Clerodendrum Splendens in hydrochloric acid solution using multiple regression and artificial neural network are presented in Table 4 and displayed in Figures 4 and 5.

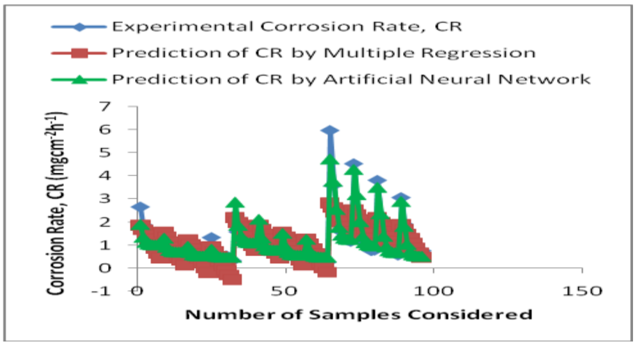


Figure 4: Comparison of error for the prediction of corrosion inhibition of mild steel by thoroughly crushed leaves of Clerodendrum Splendens in hydrochloric acid using multiple regression, MR and artificial neural network, ANN

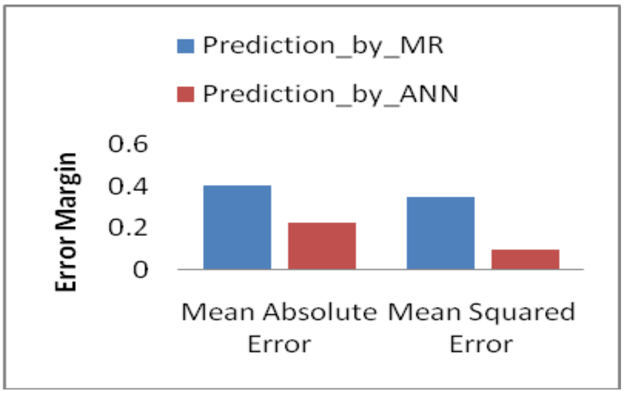


Figure 5: Error graph for the prediction of corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed leaves of Clerodendrum Splendens using multiple regression, MR and artificial neural network, ANN

The results show that the predictions by the artificial neural network gave a minimal error and were closer to the experimental corrosion rate values in comparison with the predictions by multiple regression.

3.3 Effect of temperature

The results of the variation in temperature between 298K and 358K on the corrosion of mild steel without and with the addition of the crushed fresh leaves of Clerodendrum Splendens at 15g per litre of 0.7M HCl solution are presented in Table 5 and displayed in Figure 6. The activation energy for the corrosion of mild steel in the un-inhibited solution of 0.7M HCl was 20,908.68J whilst the addition of the crushed leaves of Clerodendrum Splendens at 15g per litre of 0.7M HCl increased the activation energy to 26,212.44J. The higher value of activation energy obtained by the introduction of the Clerodendrum Splendens's pounded leaves to the corrodent suggests that greater energy needs to be reached before further corrosion can take place.

Table 5: Effect of variation in temperature on the corrosion of mild steel coupons immersed in 0.7M HCl without and with 15g of thoroughly crushed Clerodendrum Splendens's fresh leaves

Temp (K)	$CR_{CS\ addition}$ ($mgcm^{-2}h^{-1}$)	CR_{Blank} ($mgcm^{-2}h^{-1}$)	Log $CR_{CS\ addition}$	Log CR_{Blank}	1/T (K^{-1})
298	0.5468	1.6127	-0.2622	0.2076	0.003356
318	1.8994	5.4985	0.2786	0.7402	0.003145
338	2.5832	6.4186	0.4122	0.8074	0.002959
358	3.4220	7.0779	0.5343	0.8499	0.002793

$Slope_{Blank}$ = $-1092K^{-1}$ **$Slope_{CS\ addition}$** = $-1369K^{-1}$
Activation Energy, Q = 20,908.68J **Activation Energy, Q** = 26,212.44J

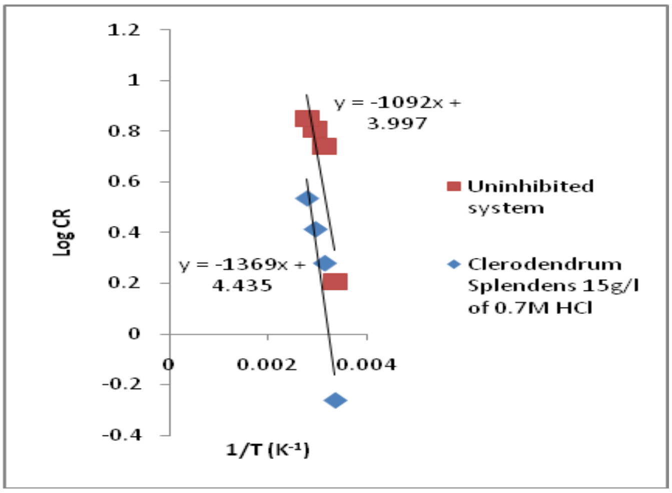


Figure 6: Arrhenius plot for the effect of variation in temperature on the corrosion of mild steel coupons immersed in 0.7M HCl without and with 15g of thoroughly crushed Clerodendrum Splendens's fresh leaves

3.4 Adsorption isotherm

According to **[12]**, the adsorption process is influenced by the chemical structures of organic compounds, the distribution of charge in molecule, the nature and surface charge of metal and the type of aggressive media. Langmuir, Freundlich, Temkin and El-Awady adsorption isotherms were tested and illustrated in Table 6 and Figure 7. The results show that the inhibition of mild steel in hydrochloric acid solution by the crushed leaves of Clerodendrum Splendens obeys the Langmuir adsorption isotherm which is given in equ. 8 with R^2 = 0.997.

$$\frac{C}{\theta} = C + \frac{1}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where,
θ is the fraction of surface coverage,
C is the inhibitor concentration, and
K is the equilibrium constant for the adsorption/desorption process.

Table 6: Calculated parameters of four adsorption isotherm models for adsorption of the thoroughly crushed fresh leaves of Clerodendrum Splendens onto the surface of mild steel in hydrochloric acid medium.

Adsorption Isotherm							
Langmuir		Freundlich		Temkin		El-Awady	
Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
1.443	0.997	0.015	0.114	0.010	0.120	0.049	0.125
Parameters							
C (g)	Log C	In C	θ	C/ θ	Log θ	1- θ	Log (θ/1-θ)
15	1.1761	2.7081	0.6674	22.4753	-0.1756	0.3326	0.3025
30	1.4771	3.4012	0.6496	46.1823	-0.1874	0.3504	0.2681
45	1.6532	3.8067	0.6841	65.7799	-0.1649	0.3159	0.3356

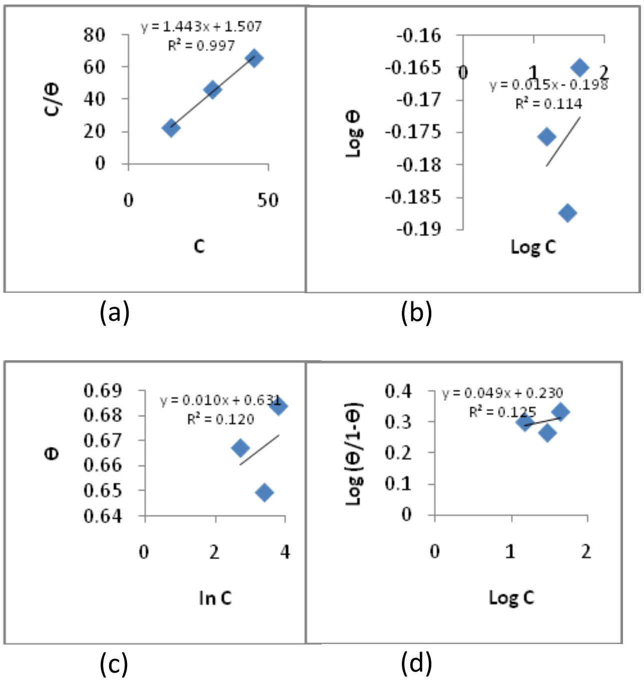


Figure 7: Adsorption isotherm models for adsorption of the thoroughly crushed fresh leaves of Clerodendrum Splendens on the mild steel surface in hydrochloric acid medium: (a) Langmuir Adsorption Isotherm; (b) Freundlich Adsorption Isotherm (c) Temkin Adsorption Isotherm (d) El-Awady Adsorption Isotherm

The Langmuir adsorption isotherm describes quantitatively the formation of a monolayer adsorbate on the outer surface of the adsorbent, and after that no further adsorption takes place **[9].**

3.5 Phytochemical analysis of Clerodendrum Splendens leaves

The phytochemical analysis of the leaves of Clerodendrum Splendens as shown in Table 7 reveals the presence of alkanoid (5.4%), tannin (3.093%), saponin (6.91%), phytate (1.083%), flavonoid (3.40%) and phenol (21.78ppm). The presence of alkanoid, flavonoid, tannin, saponin and phenol in the leaves of Clerodendrum Splendens was in agreement with the previous report by **[10].** These natural constituents may be responsible for adsorbing on the surface of the mild steel thereby effecting corrosion inhibition.

Table 7: Result of the phytochemical analysis conducted on the leaves of Clerodendrum Splendens

Plant Leaves	Compounds					
	Saponin (%)	Tannin (%)	Flavonoid (%)	Alkanoid (%)	Phytate (%)	Phenol (ppm)
Dry	6.91	3.093	3.4	5.4	1.083	21.78
Fresh	4.38	0.879	1.40	3.80	0.288	19.60

3.6 FTIR analysis

The FTIR spectrum of the adhered constituents of Clerodendrum Splendens's fresh-leaf extract on the surface of mild steel coupon immersed at 30g per litre of 0.7M HCl for eight hours is shown in Figure 8. The sharp band around 3652.8cm^{-1} reveals the absorption that is associated with the stretching vibration of hydrogen atoms bonded to oxygen (O–H stretching vibration). The C≡C and C=C stretching vibrations of alkynes and alkenes are identified at frequencies 2113.4cm^{-1} and 1625.1cm^{-1} respectively. Because of the sharp bands between 2150cm^{-1} and 2100cm^{-1}, the identified alkynes are asymmetrical in nature. On the other hand, the sharp band at 1625.1cm^{-1} being closer to 1600cm^{-1} than 1660cm^{-1} indicates the presence of conjugated alkenes.

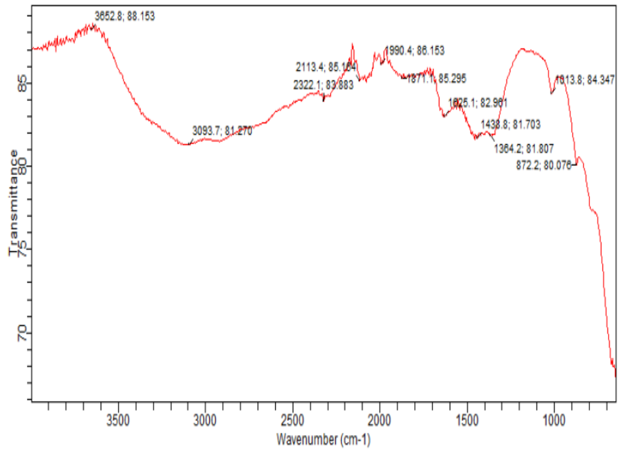
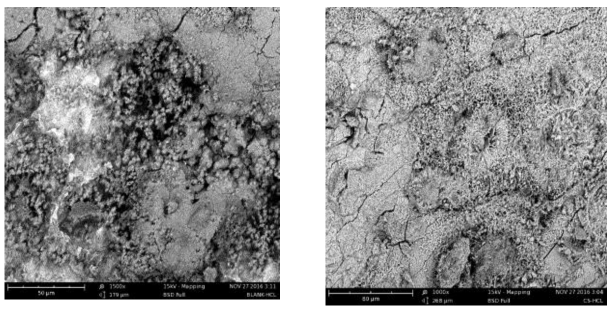


Figure 8: FTIR spectrum of film on mild steel surface after immersion for eight hours in a medium containing the thoroughly crushed fresh leaves of Clerodendrum Splendens at 30g per litre of 0.7M HCl

3.7 SEM micrograph for the corrosion inhibition of mild steel in hydrochloric acid solution by the crushed leaves of Clerodendrum Splendens

The SEM image in Figure 9(a) shows that corrosion was not uniform on the surface of mild steel when immersed in the uninhibited solution of 0.7M HCl but the addition of thoroughly crushed leaves of Clerodendrum Splendens at 30g per litre of 0.7M HCl clearly inhibited the mild steel from corrosion as revealed in Figure 9(b).



(a) (b)

Figure 9: SEM Characteristics of the Corroded Mild Steel in; (a) the blank solution of 0.7M HCl (b) the presence of thoroughly pounded fresh leaves of Clerodendrum Splendens at 30g per litre of 0.7M HCl

4.0 CONCLUSION

1. The addition of the crushed leaves of Clerodendrum Splendens reduced the corrosion of mild steel and the corrosion rate increased with increase in acid concentration whilst the inhibition efficiency improved as the experimentation progressed.

2. The maximum inhibition efficiency of 70.70% was achieved when the thoroughly pounded leaves of Clerodendrum Splendens were added at 45g per litre of 1.2M HCl.

3. The comparison of error results for the prediction of corrosion inhibition of mild steel by the crushed leaves of Clerodendrum Splendens in hydrochloric acid solution using multiple regression and artificial neural network show that the predictions by the artificial neural network gave a minimal error and were closer to the experimental corrosion rate values in comparison with the predictions by multiple regression.

4. The FTIR spectrum of the adhered constituents of Clerodendrum Splendens's fresh-leaf extract on the surface of mild steel coupon immersed at 30g per litre of 0.7M HCl for eight hours revealed the stretching vibrations of O–H, C≡C and C=C bonds.

5. The SEM image shows that corrosion was not uniform on the surface of mild steel when immersed in the uninhibited solution of 0.7M HCl but the addition of crushed leaves of Clerodendrum Splendens at 30g per litre of 0.7M clearly inhibited the mild steel from corrosion.

ACKNOWLEDGMENT: The authors are pleased to acknowledge the numerous scholars who have conducted studies on the use of plant extracts to inhibit the corrosion of carbon steels. We thank Elder & Mrs. K. I. Ndukwe for their encouragement and financial support.

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Appendix 1: Prediction of corrosion inhibition of mild steel in hydrochloric acid medium by thoroughly pounded fresh leaves of Clerodendrum Splendens

Case	t (h)	Conc_of_HCl (M)	Quantity_of_CS_Crushed_Leaves (g)	Exp. Corrosion Rate, CR ($mgcm^{-2}h^{-1}$)	Prediction_by_MR		Prediction_by_ANN	
					CR	Error	CR	Error
1	1	0.7	0	2.6487	1.86873	0.77997	1.8932	0.7555
2	2	0.7	0	1.8646	1.66437	0.20023	1.3362	0.5284
3	3	0.7	0	1.3989	1.46001	-0.06111	1.1184	0.2805
4	4	0.7	0	1.4137	1.25565	0.15805	1.0391	0.3746
5	5	0.7	0	1.4214	1.05129	0.37011	1.0129	0.4085
6	6	0.7	0	1.3684	0.84693	0.52147	1.0072	0.3612
7	7	0.7	0	1.3924	0.64257	0.74983	1.0096	0.3828
8	8	0.7	0	1.3934	0.43821	0.95519	1.0150	0.3784
9	1	0.7	15	1.0078	1.5554	-0.5476	1.2975	-0.2897
10	2	0.7	15	0.7232	1.35104	-0.62784	0.9101	-0.1869
11	3	0.7	15	0.4957	1.14668	-0.65098	0.7687	-0.273
12	4	0.7	15	0.5061	0.94232	-0.43622	0.7192	-0.2131
13	5	0.7	15	0.4728	0.73796	-0.26516	0.7037	-0.2309
14	6	0.7	15	0.4579	0.5336	-0.0757	0.7014	-0.2435
15	7	0.7	15	0.4070	0.32924	0.07776	0.7043	-0.2973
16	8	0.7	15	0.3050	0.12488	0.18012	0.7093	-0.4043
17	1	0.7	30	1.1588	1.24207	-0.08327	0.9466	0.2122
18	2	0.7	30	0.6114	1.03771	-0.42631	0.6733	-0.0619
19	3	0.7	30	0.5867	0.83335	-0.24665	0.5766	0.0101
20	4	0.7	30	0.538	0.62899	-0.09099	0.5422	-0.0042
21	5	0.7	30	0.5251	0.42463	0.10047	0.5305	-0.0054
22	6	0.7	30	0.5334	0.22027	0.31313	0.5274	0.0060
23	7	0.7	30	0.4829	0.01591	0.46699	0.5278	-0.0449
24	8	0.7	30	0.4070	-0.18845	0.59545	0.5295	-0.1225
25	1	0.7	45	1.3215	0.92874	0.39276	0.8205	0.5010

26	2	0.7	45	0.6186	0.72438	-0.10578	0.5912	0.0274
27	3	0.7	45	0.4724	0.52002	-0.04762	0.5106	-0.0382
28	4	0.7	45	0.3318	0.31566	0.01614	0.4815	-0.1497
29	5	0.7	45	0.3102	0.1113	0.19890	0.4708	-0.1606
30	6	0.7	45	0.5344	-0.09306	0.62746	0.4671	0.0673
31	7	0.7	45	0.4012	-0.29742	0.69862	0.4662	-0.0650
32	8	0.7	45	0.3166	-0.50178	0.81838	0.4663	-0.1497
33	1	1.2	0	2.2857	2.19111	0.09459	2.8584	-0.5727
34	2	1.2	0	1.5683	1.98675	-0.41845	1.8537	-0.2854
35	3	1.2	0	1.1109	1.78239	-0.67149	1.3750	-0.2641
36	4	1.2	0	1.1753	1.57803	-0.40273	1.1893	-0.0140
37	5	1.2	0	1.1838	1.37367	-0.18987	1.1215	0.0623
38	6	1.2	0	1.0470	1.16931	-0.12231	1.0992	-0.0522
39	7	1.2	0	1.0447	0.96495	0.07975	1.0945	-0.0498
40	8	1.2	0	0.9276	0.76059	0.16701	1.0968	-0.1692
41	1	1.2	15	1.3999	1.87778	-0.47788	2.1156	-0.7157
42	2	1.2	15	0.9947	1.67342	-0.67872	1.3039	-0.3092
43	3	1.2	15	0.7445	1.46906	-0.72456	0.9635	-0.2190
44	4	1.2	15	0.7326	1.2647	-0.5321	0.8393	-0.1067
45	5	1.2	15	0.8632	1.06034	-0.19714	0.7963	0.0669
46	6	1.2	15	0.7788	0.85598	-0.07718	0.7839	-0.0051
47	7	1.2	15	0.6954	0.65162	0.04378	0.7835	-0.0881
48	8	1.2	15	0.5384	0.44726	0.09114	0.7877	-0.2493
49	1	1.2	30	1.4434	1.56445	-0.12105	1.5082	-0.0648
50	2	1.2	30	0.8074	1.36009	-0.55269	0.9108	-0.1034
51	3	1.2	30	0.6177	1.15573	-0.53803	0.6824	-0.0647
52	4	1.2	30	0.6237	0.95137	-0.32767	0.6014	0.0223
53	5	1.2	30	0.582	0.74701	-0.16501	0.5731	0.0089
54	6	1.2	30	0.4957	0.54265	-0.04695	0.5641	-0.0684
55	7	1.2	30	0.3576	0.33829	0.01931	0.5627	-0.2051
56	8	1.2	30	0.3256	0.13393	0.19167	0.5643	-0.2387
57	1	1.2	45	0.6738	1.25112	-0.57732	1.2495	-0.5757
58	2	1.2	45	0.4016	1.04676	-0.64516	0.7571	-0.3555
59	3	1.2	45	0.3427	0.84240	-0.49970	0.5758	-0.2331
60	4	1.2	45	0.3601	0.63804	-0.27794	0.5118	-0.1517
61	5	1.2	45	0.2626	0.43368	-0.17108	0.4886	-0.2260
62	6	1.2	45	0.4715	0.22932	0.24218	0.4803	-0.0088
63	7	1.2	45	0.2465	0.02496	0.22154	0.4778	-0.2313
64	8	1.2	45	0.2509	-0.17940	0.43030	0.4775	-0.2266
65	1	2.2	0	5.9626	2.83587	3.12673	4.7257	1.2369
66	2	2.2	0	3.5723	2.63151	0.94079	3.7599	-0.1876
67	3	2.2	0	2.4367	2.42715	0.00955	2.5404	-0.1037
68	4	2.2	0	1.9052	2.22279	-0.31759	1.7628	0.1424
69	5	2.2	0	1.5683	2.01843	-0.45013	1.4273	0.1410
70	6	2.2	0	1.3462	1.81407	-0.46787	1.2981	0.0481
71	7	2.2	0	1.2016	1.60971	-0.40811	1.2506	-0.0490
72	8	2.2	0	1.1519	1.40535	-0.25345	1.2348	-0.0829
73	1	2.2	15	4.5220	2.52254	1.99946	4.2725	0.2495
74	2	2.2	15	2.3278	2.31818	0.00962	3.1824	-0.8546
75	3	2.2	15	1.6351	2.11382	-0.47872	2.0130	-0.3779
76	4	2.2	15	1.3258	1.90946	-0.58366	1.3637	-0.0379
77	5	2.2	15	1.0990	1.7051	-0.6061	1.1043	-0.0053
78	6	2.2	15	0.9425	1.50074	-0.55824	1.0093	-0.0668
79	7	2.2	15	0.7481	1.29638	-0.54828	0.9773	-0.2292
80	8	2.2	15	0.7711	1.09202	-0.32092	0.9694	-0.1983
81	1	2.2	30	3.8018	2.20921	1.59259	3.4965	0.3053
82	2	2.2	30	2.0025	2.00485	-0.00235	2.3535	-0.3510
83	3	2.2	30	1.5596	1.80049	-0.24089	1.3796	0.1800
84	4	2.2	30	1.3454	1.59613	-0.25073	0.9234	0.4220
85	5	2.2	30	0.9416	1.39177	-0.45017	0.7550	0.1866
86	6	2.2	30	0.7997	1.18741	-0.38771	0.6955	0.1042
87	7	2.2	30	0.6522	0.98305	-0.33085	0.6760	-0.0238
88	8	2.2	30	0.5602	0.77869	-0.21849	0.6719	-0.1117
89	1	2.2	45	3.0536	1.89589	1.15771	2.8870	0.1666
90	2	2.2	45	1.9009	1.69152	0.20938	1.8111	0.0898
91	3	2.2	45	1.2815	1.48716	-0.20566	1.0277	0.2538
92	4	2.2	45	1.1429	1.28280	-0.13990	0.6956	0.4473
93	5	2.2	45	1.0938	1.07844	0.01536	0.5774	0.5164
94	6	2.2	45	0.8940	0.87408	0.01992	0.5354	0.3586
95	7	2.2	45	0.8003	0.66972	0.13058	0.5207	0.2796
96	8	2.2	45	0.7515	0.46536	0.28614	0.5163	0.2352