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Mathematical Model for Corrosion Inhibition of Mild Steel in Hydrochloric Acid by Crushed Leaves of Tridax Procumbens (Asteraceae)

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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 Tridax Procumbens was investigated using the weight-loss method. The corrosion rate was observed to increase with increase in the concentration of acid whilst the inhibition efficiency improved with time. For the entire study environment, the addition of thoroughly crushed leaves of Tridax Procumbens at 45g per litre of 0.7M HCl produced the maximum inhibition efficiency of 76.91% with a corresponding diminution in corrosion rate from $1.1937 mg.cm^{-2}.h^{-1}$ to $0.2229 mg.cm^{-2}.h^{-1}$. 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. Four adsorption isotherm models namely: Langmuir, El-Awady, Freundlich and Temkin isotherm models were tested but, the corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed leaves of Tridax Procumbens was only in agreement with the Langmuir adsorption isotherm with R^2 = 0.929.

Keywords- *Tridax Procumbens, Crushed Leaves, Mild Steel, Multiple Regression, Hydrochloric Acid, Artificial Neural Network*

I. INTRODUCTION

Upon exposure to the environment, metals corrode and revert back to the ores from which they were won. In the corrosion process, two reactions are imminent. One is the anodic reaction, wherein metal atoms oxidize and pass into solution, allowing their electrons to occupy the metal surface. The other is the cathodic reaction, in which the free electrons within the metal react with oxygen and water in reduction reactions [1].

Corrosion can be prevented by: proper materials selection and design, coating, anodic protection, cathodic protection and use of inhibitors [2]. According to [3], an inhibitor is a chemical substance that, when added in small concentration to an environment, is able to effectively decrease the corrosion rate. In their view, [4] noted that specific chemicals can be added to an electrolyte to reduce diffusion of ions in the metal-electrolyte interface and enhance the polarization of one or both electrical reactions.

In many cases, the corrosion that occurs as a result of insufficient addition of the inhibitor may be more severe than in the complete absence of the inhibitor. The depletion of the inhibitor may occur for a variety of reasons. In the initial stages of use, for instance, after the first application, the inhibitor concentration may reduce rapidly due to its reaction with contaminants in the system and also as a result of protective film formation. However, the initial concentrations of the inhibitor are often recommended to be at higher levels than subsequent additions. In order to be effective, all inhibitors should be present above a certain minimum concentration [5].

Unfortunately, the use of some chemical inhibitors has been limited either because of high toxicity or expensive cost of synthesis [6, 7]. This development has necessitated the search for alternative inhibitors that are not just environmentally friendly and effective but inexpensive. These nontoxic and inexpensive corrosion inhibitors have been found in different parts of plant extracts [8, 9].

This present work aims at studying the effectiveness of thoroughly crushed leaves of Tridax Procumbens in inhibiting the corrosion of mild steel in hydrochloric acid. Flowering plants of Tridax Procumbens are found year-round in Sri Lanka [10] but shorter flowering periods are reported for West Africa. In East Africa, flowering occurs 35 to 55 days after emergence, and seeds ripen within 3 weeks of flowering [11]. Tridax Procumbens can either be cross- or self-pollinated [12]. Insect pollinators include thrips, beetles, and bees [13] and butterflies [14]. Essential oils extracted from Tridax procumbens are reported to have insecticidal activity against musca domestica, culex quinquefasciatus, dysdercus similis and supella spp. [15]. Aqueous extracts inhibit aflatoxin production by aspergillus flavus [16] and a petroleum ether extract from flowers protects cowpea seeds from damage by the bruchid callosobruchus maculatus [17]. Tridax Procumbens is sometimes used as green feed for livestock and poultry in Nigeria [18]. The phytochemical analysis of the leaves of Tridax Procumbens as reported by [22], revealed the presence of alkanoid, phytate, saponin, flavonoid and tannin.

The use of mathematical model in analysing the corrosion inhibition process offers a better understanding of the rate at which corrosion takes place and how certain parameters can be varied to prevent corrosion. Multiple regression is a veritable mathematical tool for developing predictive models. It is used to predict the dependent variable based on the assessment of two or more independent variables [19, 20]. On the other hand, artificial neural network manages information in the same manner as the human brain to predict a target variable vis-à-vis other independent variables.

II. MATERIALS AND METHODS

A. *Fabrication of Mild Steel Coupons*

Mild steel coupons of 4cm x 4cm dimensions were cut from a flat sheet metal of 0.15cm thickness with the composition: (wt %) C=0.20%, Zn=0.75%, Ti=0.28, Mn=0.23%, S=0.04%, P=0.035% and Fe balance. The coupons were first abraded with coarse and fine emery papers, treated with acetone and dried before obtaining their initial weights.

B. *Preparation of Crushed Plant Leaves*

The leaves of Tridax Procumbens were gotten from the proximity of the Federal University of Technology Owerri, Imo State, Nigeria and thoroughly crushed using a manual blender. The crushed leaves were added at 15g per litre, 30g per litre and 45g per litre of 0.7M, 1.2M and 2.2M HCl. The moisture level of the plant's leaves was 63.50% as at the time the experiment was conducted.

C. *Weight-loss Measurements*

The coupons were immersed in different study environments of 0.7M, 1.2M and 2.2M HCl to which various quantities of thoroughly crushed leaves of Tridax Procumbens had been added at 15g per litre, 30g per litre and 45g per litre of the acid concentration. A set-up, bearing no crushed leaves was prepared for the purpose of comparison. After every hour, a coupon is withdrawn from the system, cleaned with acetone, dried and re-weighed to obtain the final weight. Each experimental set-up spanned for eight hours. The above experimental procedure was repeated by varying the temperature between 298K and 358K.

The corrosion rate was computed using the following relationship:

Corrosion rate, $C_{orr}R\,(mg.cm^{-2}.h^{-1}) = w/A*t$ (1)

Where,

w = weight loss in mg.

A = Exposed area in cm^2.

t = Exposure time in hours.

By comparing the corrosion rate of the uninhibited medium with that of the inhibited system, the inhibition efficiency was obtained by the formula:

$I.E\,(\%) = ((C_{orr}R_1 - C_{orr}R_2)/C_{orr}R_1)*100$ (2)

Where,

$C_{orr}R_1$ = Corrosion rate of the uninhibited system.

$C_{orr}R_2$ = Corrosion rate of the inhibited system.

D. *Mathematical Model Development*

1) *Multiple Regression (MR)*

Multiple regression is a statistical method that is employed to develop a predictive model. The predictive model is formulated by comparing the dependent variable with two or more independent variables. By evaluating the dependent variable (corrosion rate ($mg.cm^{-2}.h^{-1}$)) with three independent variables namely: time of exposure (h), concentration of acid (M) and quantity of crushed leaves (g), the predictive model is expressed thus:

$C_{orr}R = \varrho_o + h_a(\text{time of exposure}) + h_b(\text{conc. of acid}) + h_c(\text{quantity of crushed leaves})$ (3)

Where,

ϱ_o = Intercept on $C_{orr}R$ axis.

h_a = Change in $C_{orr}R$ for each increment change in time of exposure.

h_b = Change in $C_{orr}R$ for each increment change in concentration of acid.

h_c = Change in $C_{orr}R$ for each increment change in quantity of crushed leaves.

2) *Artificial Neural Network (ANN)*

Artificial neural network (ANN) utilizes the information-processing technique of the human brain in analysing data. An ANN consists of interconnected processing units. The general model of a processing unit consists of the 'summing part' followed by the 'output component'. The summing section receives input values, assigns a weight to each value, and computes the weighted sum. The sign of the weight for each input determines whether the input is positive or negative. The output component produces a signal from the weighted sum [21]. The artificial neural network representing inputs and output for the corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed leaves of Tridax Procumbens is shown in Figure 1.

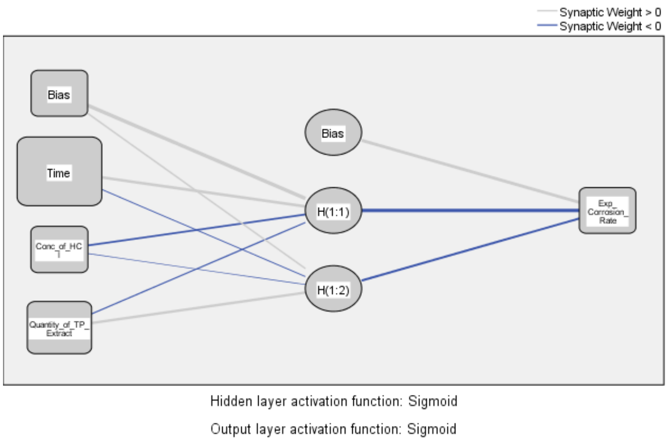


Figure 1. Artificial neural network model representing inputs and output for the corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed leaves of Tridax Procumbens

The net output is given thus:

$$ɧ_j = f(ɧ_{Input}) \quad (4)$$

$$ɧ_{Input} = ꞡ_j + \sum(ƙ_i ɳ_{ij}) \quad (5)$$

$$f(x) = 1/(1+e^{-ɧ_{input}}) \quad (6)$$

Where,

$ɧ_j$ = Net output.

$ɧ_{Input}$ = Net input.

$ƙ_i$ = Input of the unit

$ꞡ_j$ = Bias of the unit.

$ɳ_{ij}$= Weight of the unit.

f = Activation function.

3) *Error in Prediction*

The two veritable methods of investigating the error in prediction are the mean square error (MSE) and the mean absolute error (MAE). They are employed to figure out how close the predicted value is to the real value. Mathematically, they are expressed thus:

$$MAE = (1/ɳ)\sum(ʠ_i - ʐ_i) \quad (7)$$

$$MSE = (1/ ɳ)\sum(ʠ_i - ʐ_i)^2 \quad (8)$$

Where,

$ʠi$ = Predicted value.

$ʐi$ = Real value.

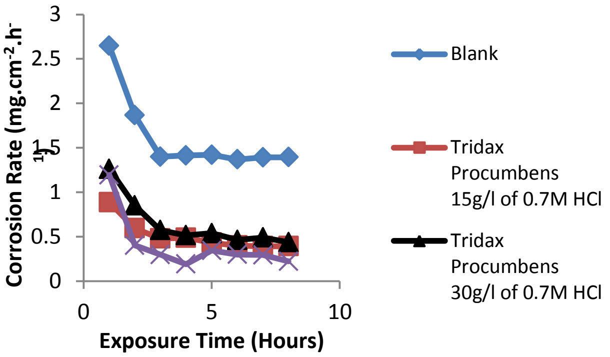
$ɳ$ = Number of samples considered.

III. RESULTS

TABLE I. EFFECT OF ADDITION OF THOROUGHLY CRUSHED LEAVES OF TRIDAX PROCUMBENS ON THE CORROSION OF MILD STEEL IMMERSED IN DIFFERENT CONCENTRATIONS OF HYDROCHLORIC ACID

T (h)	0.7M HCl		1.2M HCl		2.2M HCl	
	CR ($mg.cm^{-2}.h^{-1}$)	I.E (%)	CR ($mg.cm^{-2}.h^{-1}$)	I.E (%)	CR ($mg.cm^{-2}.h^{-1}$)	I.E (%)
Addition of thoroughly crushed leaves of Tridax Procumbens at 15g/l of HCl						
1	0.8887	66.45	1.6526	27.70	4.6005	22.84
2	0.5954	68.07	1.1792	24.81	2.3946	32.97
3	0.4802	65.67	0.6845	38.38	1.5084	38.10
4	0.4887	65.43	0.8081	31.24	1.1770	38.22
5	0.4322	69.59	0.7197	39.20	0.9985	36.33
6	0.4008	70.71	0.6622	36.75	0.9071	32.62
7	0.3942	71.69	0.6626	36.58	0.7808	35.02
8	0.3928	71.81	0.6190	33.27	0.7686	33.28
Av.	0.5091	68.68	0.8735	33.49	1.6419	33.67
Addition of thoroughly crushed leaves of Tridax Procumbens at 30g/l of HCl						
1	1.2634	52.30	1.4144	33.12	4.6585	21.88
2	0.8510	54.36	0.9322	40.56	2.4367	31.79
3	0.5741	58.96	0.6632	40.30	1.5935	34.60
4	0.5162	63.49	0.5402	54.04	1.0238	46.26
5	0.5390	62.08	0.5733	51.57	0.9189	41.41
6	0.4642	66.08	0.4807	54.09	0.7779	42.22
7	0.4912	64.72	0.3784	63.78	0.6925	42.37
8	0.4389	68.50	0.3478	62.51	0.4734	58.90
Av.	0.6423	61.31	0.6663	50.00	1.5719	39.93
Addition of thoroughly crushed leaves of Tridax Procumbens at 45g/l of HCl						
1	1.1937	54.93	0.6376	72.10	3.9121	34.39
2	0.4015	78.47	0.4092	73.91	1.8965	46.91
3	0.2982	78.68	0.1123	89.89	1.2944	46.88
4	0.1920	86.42	0.2498	78.75	1.2314	35.37
5	0.3445	75.76	0.3723	68.55	1.0002	36.22
6	0.3001	78.07	0.4202	59.87	0.9192	31.72
7	0.2938	78.90	0.3867	62.98	0.7759	35.43
8	0.2229	84.00	0.2058	77.81	0.7693	33.21
Av.	0.4058	76.91	0.3492	72.98	1.4749	37.52

t = time of exposure; Av. = Average



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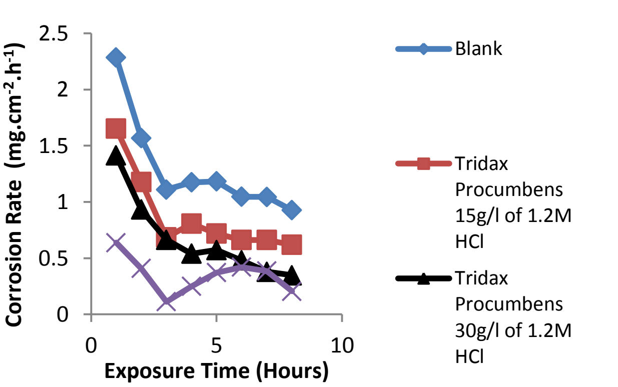

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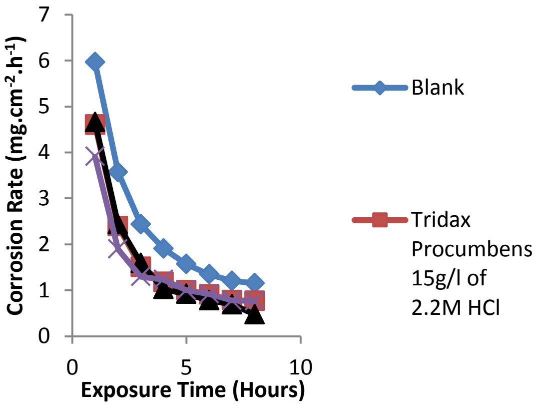
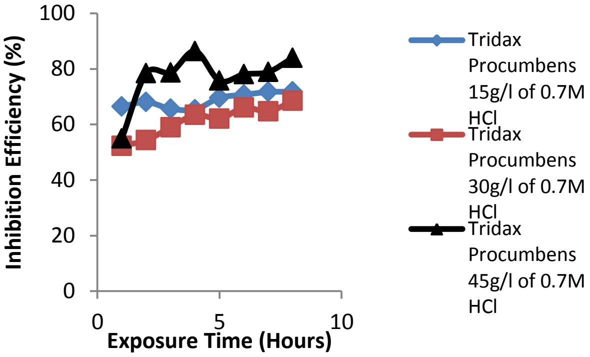


(c)

Figure 2. Effect of addition thoroughly crushed leaves of Tridax Procumbens 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



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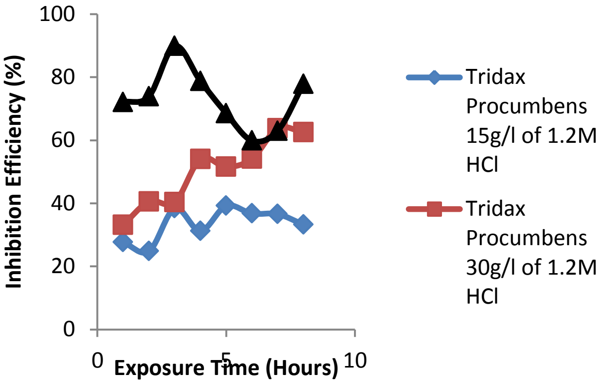

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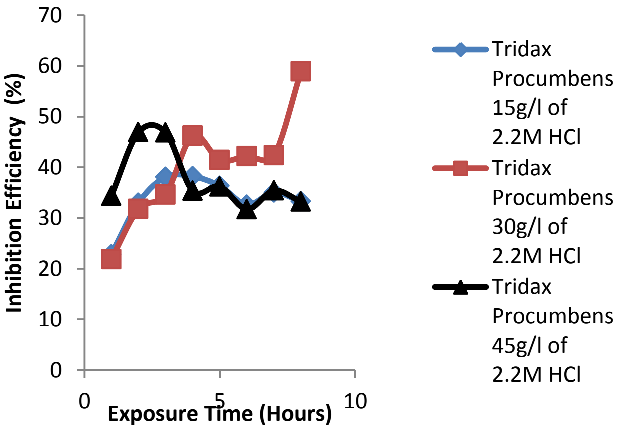

(c)

Figure 3. Tridax Procumbens's corrosion inhibition efficiency for mild steel 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

TABLE II. ANALYSIS FOR PREDICTION OF CORROSION INHIBITION OF MILD STEEL BY THOROUGHLY CRUSHED LEAVES OF TRIDAX PROCUMBENS IN HYDROCHLORIC ACID USING MULTIPLE REGRESSION (MR)

	Model Coefficients			
	Constant	Time (h)	Conc. of Acid (M)	Quantity of Crushed Leaves (g)
HCl	1.623	-0.220	0.698	-0.021

TABLE III. ANALYSIS FOR PREDICTION OF CORROSION INHIBITION OF MILD STEEL IN HYDROCHLORIC ACID MEDIUM BY THOROUGHLY CRUSHED LEAVES OF TRIDAX PROCUMBENS USING ARTIFICIAL NEURAL NETWORK (ANN)

Independent variable importance for the addition of thoroughly crushed leaves of Tridax Procumbens in hydrochloric acid	
	Importance
Time	0.466
Conc_of_HCl	0.237
Quantity_of_TP_Extract	0.297

Parameter estimates for the addition of thoroughly crushed leaves of Tridax Procumbens in hydrochloric acid				
Predictor		Predicted		
		Hidden Layer 1		Output Layer
		H(1:1)	H(1:2)	Exp_Corrosion_Rate
Input Layer	(Bias)	4.637	0.902	
	Time	2.515	-0.047	
	Conc_of_HCl	-1.274	-0.038	
	Quantity_of_TP_Extract	-0.343	2.108	
Hidden Layer 1	(Bias)			3.017
	H(1:1)			-4.060
	H(1:2)			-1.948

TABLE IV. ERROR ANALYSIS FOR THE PREDICTION OF CORROSION INHIBITION OF MILD STEEL BY THOROUGHLY CRUSHED LEAVES OF TRIDAX PROCUMBENS IN HYDROCHLORIC ACID 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	0.450778438	0.223672917
Mean Squared Error	0.419030425	0.095323453

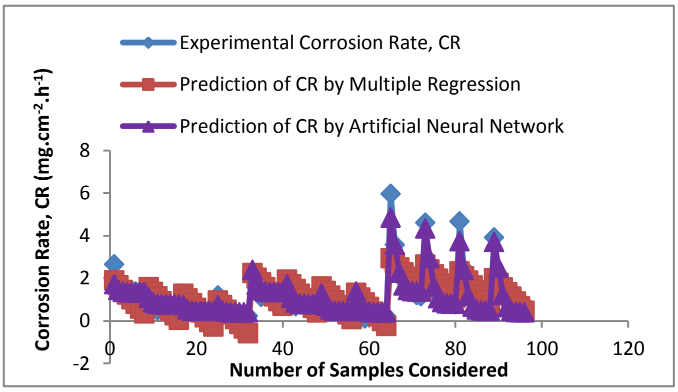

Figure 4. Comparison of error for the prediction of corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed leaves of Tridax Procumbens using multiple regression, MR and artificial neural network, ANN

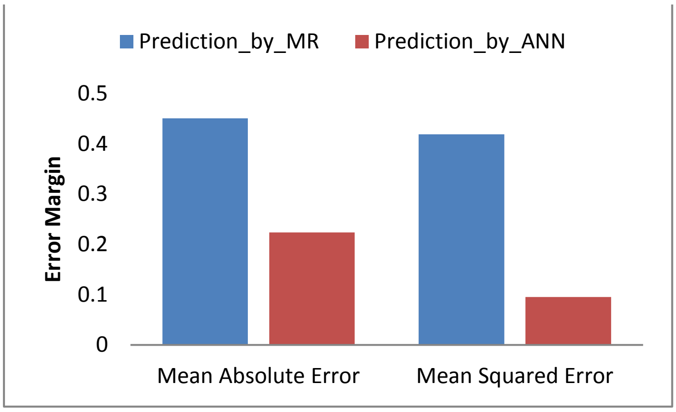

Figure 5. Error graph for the prediction of corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed leaves of Tridax Procumbens using Multiple Regression, MR and Artificial Neural Network, ANN

TABLE V. EFFECT OF VARIATION IN TEMPERATURE ON THE CORROSION OF MILD STEEL COUPONS IMMERSED AT 15G OF TRIDAX PROCUMBENS'S THOROUGHLY CRUSHED LEAVES PER LITRE OF 0.7M HCL

T (K)	$CR_{TP\ addition}$ ($mg.cm^{-2}.h^{-1}$)	CR_{Blank} ($mg.cm^{-2}.h^{-1}$)	Log $CR_{TP\ addition}$	Log CR_{Blank}	1/T (K^{-1})
298	0.5091	1.6127	-0.2932	0.2076	0.003356
318	1.8626	5.4985	0.2701	0.7402	0.003145
338	2.5854	6.4186	0.4125	0.8074	0.002959
358	3.2481	7.0779	0.5116	0.8499	0.002793

$Slope_{Blank}$ = -1092K^{-1}; Activation Energy, Q = 20,908.68J
$Slope_{TP\ addition}$ = -1389K^{-1}; Activation Energy, Q = 26,595.38J

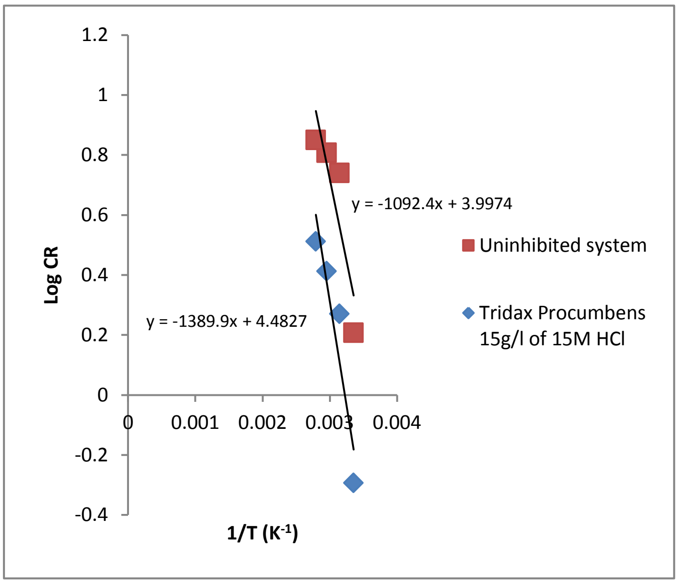

Figure 6. Arrhenius plot for the effect of addition of thoroughly crushed leaves of Tridax Procumbens on corrosion of mild steel coupons immersed at 15g/l of 0.7M HCl

TABLE VI. CALCULATED PARAMETERS OF FOUR ADSORPTION ISOTHERM MODELS FOR ADSORPTION OF THOROUGHLY CRUSHED LEAVES OF TRIDAX PROCUMBENS 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
1.222	0.929	0.074	0.132	0.055	0.155	0.289	0.186
Parameters							
C (g)	Log C	In C	Θ	C/ Θ	Log Θ	1- Θ	Log (Θ/1-Θ)
15	1.1761	2.7081	0.6868	21.8404	-0.1632	0.3132	0.3410
30	1.4771	3.4012	0.6131	48.9317	-0.2125	0.3869	0.1999
45	1.6532	3.8067	0.7691	58.5099	-0.1140	0.2309	0.5226

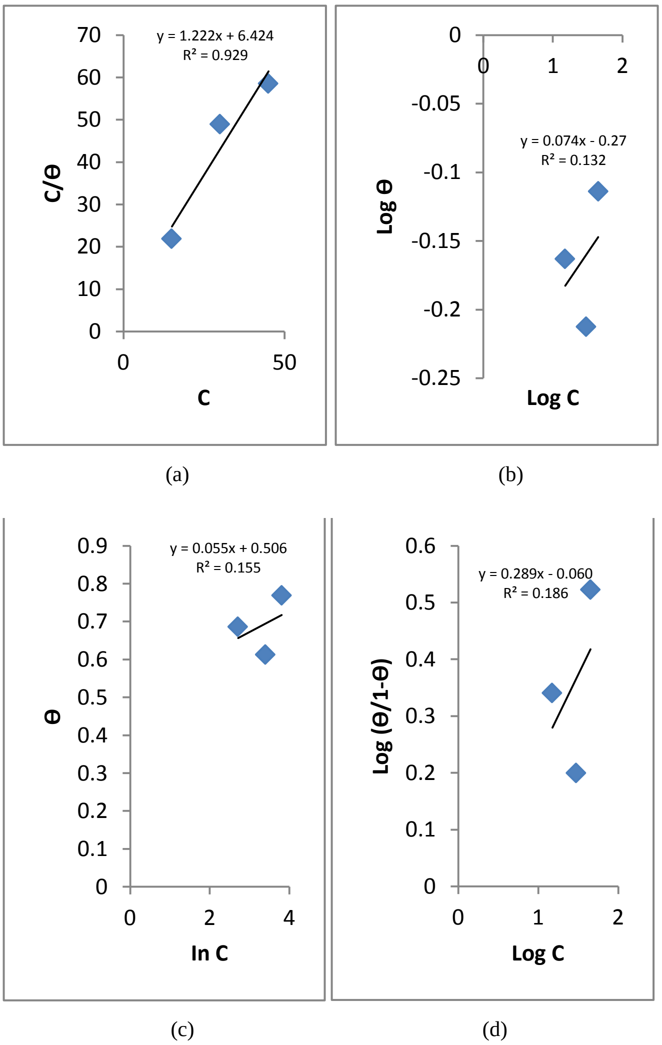

Figure 7. Adsorption isotherm models for adsorption of thoroughly crushed leaves of Tridax Procumbens on the mild steel surface in hydrochloric acid medium: (a) Langmuir adsorption isotherm; (b) Freundlich adsorption isotherm (c) Temkin adsorption isotherm (d) El-Awady adsorption isotherm

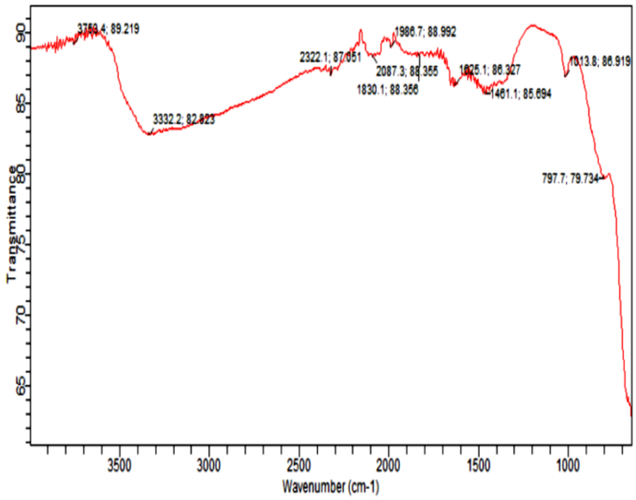

Figure 8. FTIR spectrum of film on mild steel surface after immersion in a medium containing thoroughly crushed fresh-leaves of Tridax Procumbens at 30g per litre of 0.7M HCl

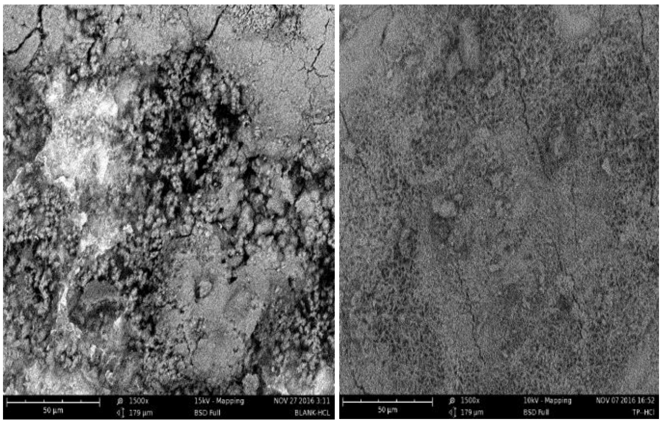

Figure 9. SEM Characteristics of the Corroded Mild Steel in: (a) the blank solution of 0.7M HCl (b) the presence of thoroughly crushed leaves of Tridax Procumbens at 30g/l of 0.7M HCl

IV. DISCUSSION OF RESULTS

A. Effect of Addition of thoroughly Crushed Leaves of Tridax Procumbens on the Corrosion of Mild Steel Coupons Immersed in Hydrochloric Acid

The average corrosion rate, CR and inhibition efficiency, I.E in the order CR (I.E) as presented in Table 1 for the addition of thoroughly crushed leaves of Tridax Procumbens at 15g per litre of 0.7M, 1.2M and 2.2M HCl gave the following: 0.5091mg.cm^{-2}.h^{-1} (68.68%) in 0.7M HCl; 0.8735mg.cm^{-2}.h^{-1} (33.49%) in 1.2M HCl and 1.6419mg.cm^{-2}.h^{-1} (33.67%) in 2.2M HCl. By increasing the crushed leaves to 30g per litre of various acid concentrations, the corresponding average corrosion rate and inhibition efficiency were: 0.6423mg.cm^{-2}.h^{-1} (61.31%) in 0.7M HCl; 0.6663mg.cm^{-2}.h^{-1} (50.00%) in 1.2M HCl and 1.5719mg.cm^{-2}.h^{-1} (39.93%) in 2.2M HCl. Further addition of the crushed leaves at 45g per litre of different acid concentrations gave the following average corrosion rate and inhibition efficiency: 0.4058mg.cm^{-2}.h^{-1} (76.91%) in 0.7M HCl; 0.3492mg.cm^{-2}.h^{-1} (72.98%) in 1.2M HCl and 1.4749mg.cm^{-2}.h^{-1} (37.52%) in 2.2M HCl. The corrosion rate was observed to increase with increase in acid concentration whilst the inhibition efficiency improved with time.

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 Tridax Procumbens's crushed fresh-leaves. The corrosion-rate curve decreased progressively with increase in exposure time. The corrosion rate, in all the studied environments, was lower in the presence of Tridax Procumbens's crushed leaves than in the blank acid solution. On the order hand, the inhibition efficiency curves gradually increased with increase in the exposure time. For the entire study environment, the addition of thoroughly crushed leaves of Tridax Procumbens at 45g per litre of 0.7M HCl produced the highest inhibition efficiency of 76.91% with a corresponding corrosion rate reduction from 1.1937mg.cm^{-2}.h^{-1} to 0.2229mg.cm^{-2}.h^{-1}.

B. *Prediction of Corrosion Inhibition of Mild Steel in Hydrochloric Acid by thoroughly Crushed Leaves of Tridax Procumbens*

The prediction of the corrosion rate of mild steel in hydrochloric acid with and without the addition of thoroughly crushed leaves of Tridax Procumbens was achieved using multiple regression and artificial neural network. The predicted values are presented in Appendix 1.

Using multiple regressions as illustrated in Table 2, the predictive equation for the corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed fresh-leaves of Tridax Procumbens is stated thus:

$$CR_{TP\ in\ HCl\ by\ MR} = 1.623 - 0.220(\text{time}) + 0.698(\text{conc. of acid}) - 0.021(\text{quantity of crushed leaves}) \quad (9)$$

On the other hand, the prediction of the experimental corrosion rate by the artificial neural network revealed the importance of the three independent variables; (time (h), concentration of acid (M) and quantity of crushed leaves (g)) in the prediction of the dependent variable (Corrosion rate, CR (mg.cm^{-2}.h^{-1}) for the corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed leaves of Tridax Procumbens as presented in Table 3. The time of exposure largely influenced the prediction of the corrosion rate by 46.6%, followed by the quantity of crushed leaves, 29.7% and finally the concentration of acid, 23.7%.

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

C. *Effect of Variation in Temperature on the Corrosion Inhibition of Mild Steel Coupons Immersed at 15g of Tridax Procumbens's Crushed Leaves per litre of 0.7M HCl*

The result of the variation in temperature (298K, 318K, 338 and 358K) on the corrosion inhibition of mild steel with and without the addition of thoroughly crushed fresh-leaves of Tridax Procumbens at 15g per litre of 0.7M HCl is presented in Table 5 and displayed in Figure 6. The activation energy for the corrosion of mild steel in the blank solution of 0.7M HCl was 20,908.68J while the addition of thoroughly crushed fresh-leaves of Tridax Procumbens at 15g per litre of 0.7M HCl gave higher activation energy of 26,595.38J. The higher value of activation energy obtained by the introduction of Tridax Procumbens's crushed leaves to the corrodent suggests that greater energy needs to be attained before further corrosion can take place.

D. *Adsorption Isotherm for the Corrosion Inhibition of Mild Steel in Hydrochloric acid by thoroughly Crushed Leaves of Tridax Procumbens*

Four adsorption isotherm models namely: Langmuir, El-Awady, Freundlich and Temkin isotherm models were tested. The corrosion inhibition of mild steel in hydrochloric acid by thoroughly crushed leaves of Tridax Procumbens conforms only with the Langmuir adsorption isotherm with $R^2 = 0.929$ as illustrated in Table 6 and Figure 7. This development indicates the adsorption of a monolayer of the inhibitive constituents of thoroughly crushed fresh-leaves of Tridax Procumbens on the surface of mild steel.

E. *FTIR Analysis of the Corrosion Inhibition of Mild Steel in Hydrochloric Acid by thoroughly Crushed Leaves of Tridax Procumbens.*

Figure 8 shows the FTIR spectrum of the adhered constituents of Tridax Procumbens's crushed leaves on the surface of mild steel coupon immersed at 30g per litre of 0.7M HCl for eight hours. The sharp band around 3600cm^{-1} indicates the presence of the O–H functional group. The N–H stretch of amine is spotted around 3332.2cm^{-1}. The two spikes at 3332.2cm^{-1} indicate the presence of primary amines. The C≡C and C=C stretching vibrations of alkynes and alkenes are identified at frequencies 2087.3cm^{-1} and 1625.1cm^{-1} respectively. In addition, since the frequency, 1625.1cm^{-1} is closer to 1600cm^{-1} than $1660cm^{-1}$ the presence of conjugated alkenes is identified.

F. *SEM Micrograph for the Corrosion Inhibition of Mild Steel in Hydrochloric Acid by thoroughly Crushed Leaves of Tridax Procumbens*

The SEM image shows that the deterioration of the surface of mild steel in an uninhibited solution of 0.7M HCl is not uniform. However, the addition of thoroughly crushed leaves of Tridax Procumbens at 30g per litre of 0.7M HCl clearly protected the surface of the steel from corrosion as shown in Figure 9(b).

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APPENDIX

Appendix 1: Prediction of corrosion inhibition of mild steel in hydrochloric acid medium by thoroughly crushed leaves of Tridax Procumbens

Case	Time (h)	Conc_of HCl (M)	Quantity of TP Extract (g)	Exp. Corrosion Rate($mg.cm^{-2}.h^{-1}$)	Prediction_by_MR		Prediction_by_ANN	
					CR	Error	CR	Error
1	1	0.7	0	2.6487	1.89142	0.75728	1.7147	0.934
2	2	0.7	0	1.8646	1.67146	0.19314	1.4474	0.4172
3	3	0.7	0	1.3989	1.4515	-0.0526	1.3613	0.0376
4	4	0.7	0	1.4137	1.23155	0.18215	1.3358	0.0779
5	5	0.7	0	1.4214	1.01159	0.40981	1.3305	0.0909
6	6	0.7	0	1.3684	0.79163	0.57677	1.3319	0.0365
7	7	0.7	0	1.3924	0.57168	0.82072	1.3356	0.0568
8	8	0.7	0	1.3934	0.35172	1.04168	1.3399	0.0535
9	1	0.7	15	0.8887	1.57974	-0.69104	1.0807	-0.192
10	2	0.7	15	0.5954	1.35978	-0.76438	0.8524	-0.2570
11	3	0.7	15	0.4802	1.13983	-0.65963	0.7829	-0.3027
12	4	0.7	15	0.4887	0.91987	-0.43117	0.7638	-0.2751
13	5	0.7	15	0.4322	0.69991	-0.26771	0.7614	-0.3292
14	6	0.7	15	0.4008	0.47996	-0.07916	0.7644	-0.3636
15	7	0.7	15	0.3942	0.2600	0.1342	0.7694	-0.3752
16	8	0.7	15	0.3928	0.04004	0.35276	0.775	-0.3822
17	1	0.7	30	1.2634	1.26806	-0.00466	0.7258	0.5376
18	2	0.7	30	0.851	1.0481	-0.1971	0.532	0.319
19	3	0.7	30	0.5741	0.82815	-0.25405	0.4734	0.1007
20	4	0.7	30	0.5162	0.60819	-0.09199	0.4555	0.0607
21	5	0.7	30	0.539	0.38823	0.15077	0.4506	0.0884
22	6	0.7	30	0.4642	0.16828	0.29592	0.4499	0.0143
23	7	0.7	30	0.4912	-0.05168	0.54288	0.4507	0.0405
24	8	0.7	30	0.4389	-0.27164	0.71054	0.4520	-0.0131
25	1	0.7	45	1.1937	0.95638	0.23732	0.7221	0.4716
26	2	0.7	45	0.4015	0.73642	-0.33492	0.4882	-0.0867
27	3	0.7	45	0.2982	0.51647	-0.21827	0.4185	-0.1203
28	4	0.7	45	0.192	0.29651	-0.10451	0.3965	-0.2045
29	5	0.7	45	0.3445	0.07655	0.26795	0.3895	-0.045
30	6	0.7	45	0.3001	-0.1434	0.4435	0.3873	-0.0872
31	7	0.7	45	0.2938	-0.36336	0.65716	0.3868	-0.093
32	8	0.7	45	0.2229	-0.58332	0.80622	0.3868	-0.1639
33	1	1.2	0	2.2857	2.24048	0.04522	2.3938	-0.1081
34	2	1.2	0	1.5683	2.02052	-0.45222	1.6936	-0.1253
35	3	1.2	0	1.1109	1.80057	-0.68967	1.4484	-0.3375
36	4	1.2	0	1.1753	1.58061	-0.40531	1.3697	-0.1944
37	5	1.2	0	1.1838	1.36065	-0.17685	1.3466	-0.1628
38	6	1.2	0	1.0470	1.1407	-0.0937	1.342	-0.295
39	7	1.2	0	1.0447	0.92074	0.12396	1.3435	-0.2988
40	8	1.2	0	0.9276	0.70078	0.22682	1.3471	-0.4195
41	1	1.2	15	1.6526	1.9288	-0.2762	1.7216	-0.069
42	2	1.2	15	1.1792	1.70885	-0.52965	1.0687	0.1105
43	3	1.2	15	0.6845	1.48889	-0.80439	0.8584	-0.1739
44	4	1.2	15	0.8081	1.26893	-0.46083	0.7946	0.0135
45	5	1.2	15	0.7197	1.04898	-0.32928	0.7775	-0.0578
46	6	1.2	15	0.6622	0.82902	-0.16682	0.7757	-0.1135
47	7	1.2	15	0.6626	0.60906	0.05354	0.7791	-0.1165
48	8	1.2	15	0.619	0.38911	0.22989	0.7842	-0.1652

Case	Time (h)	Conc_of HCl (M)	Quantity of TP Extract (g)	Exp. Corrosion Rate($mg.cm^{-2}.h^{-1}$)	Prediction_by_MR		Prediction_by_ANN	
					CR	Error	CR	Error
49	1	1.2	30	1.4144	1.61712	-0.20272	1.2841	0.1303
50	2	1.2	30	0.9322	1.39717	-0.46497	0.7044	0.2278
51	3	1.2	30	0.6632	1.17721	-0.51401	0.528	0.1352
52	4	1.2	30	0.5402	0.95725	-0.41705	0.4746	0.0656
53	5	1.2	30	0.5733	0.7373	-0.1640	0.4584	0.1149
54	6	1.2	30	0.4807	0.51734	-0.03664	0.4540	0.0267
55	7	1.2	30	0.3784	0.29738	0.08102	0.4536	-0.0752
56	8	1.2	30	0.3478	0.07743	0.27037	0.4545	-0.1067
57	1	1.2	45	0.6376	1.30544	-0.66784	1.3756	-0.7380
58	2	1.2	45	0.4092	1.08549	-0.67629	0.6905	-0.2813
59	3	1.2	45	0.1123	0.86553	-0.75323	0.4794	-0.3671
60	4	1.2	45	0.2498	0.64557	-0.39577	0.4161	-0.1663
61	5	1.2	45	0.3723	0.42562	-0.05332	0.3962	-0.0239
62	6	1.2	45	0.4202	0.20566	0.21454	0.3898	0.0304
63	7	1.2	45	0.3867	-0.0143	0.4010	0.3879	-0.0012
64	8	1.2	45	0.2058	-0.23425	0.44005	0.3874	-0.1816
65	1	2.2	0	5.9626	2.93861	3.02399	4.8454	1.1172
66	2	2.2	0	3.5723	2.71865	0.85365	3.5599	0.0124
67	3	2.2	0	2.4367	2.49869	-0.06199	2.2576	0.1791
68	4	2.2	0	1.9052	2.27874	-0.37354	1.6580	0.2472
69	5	2.2	0	1.5683	2.05878	-0.49048	1.4521	0.1162
70	6	2.2	0	1.3462	1.83882	-0.49262	1.3863	-0.0401
71	7	2.2	0	1.2016	1.61887	-0.41727	1.3673	-0.1657
72	8	2.2	0	1.1519	1.39891	-0.24701	1.3640	-0.2121
73	1	2.2	15	4.6005	2.62693	1.97357	4.3406	0.2599
74	2	2.2	15	2.3946	2.40697	-0.01237	2.9419	-0.5473
75	3	2.2	15	1.5084	2.18702	-0.67862	1.6117	-0.1033
76	4	2.2	15	1.1770	1.96706	-0.79006	1.0514	0.1256
77	5	2.2	15	0.9985	1.74710	-0.7486	0.8732	0.1253
78	6	2.2	15	0.9071	1.52715	-0.62005	0.8195	0.0876
79	7	2.2	15	0.7808	1.30719	-0.52639	0.8058	-0.0250
80	8	2.2	15	0.7686	1.08723	-0.31863	0.8053	-0.0367
81	1	2.2	30	4.6585	2.31525	2.34325	3.7316	0.9269
82	2	2.2	30	2.4367	2.09529	0.34141	2.3806	0.0561
83	3	2.2	30	1.5935	1.87534	-0.28184	1.1544	0.4391
84	4	2.2	30	1.0238	1.65538	-0.63158	0.6687	0.3551
85	5	2.2	30	0.9189	1.43542	-0.51652	0.5226	0.3963
86	6	2.2	30	0.7779	1.21547	-0.43757	0.4781	0.2998
87	7	2.2	30	0.6925	0.99551	-0.30301	0.4648	0.2277
88	8	2.2	30	0.4734	0.77555	-0.30215	0.4615	0.0119
89	1	2.2	45	3.9121	2.00357	1.90853	3.7027	0.2094
90	2	2.2	45	1.8965	1.78361	0.11289	2.5028	-0.6063
91	3	2.2	45	1.2944	1.56366	-0.26926	1.2089	0.0855
92	4	2.2	45	1.2314	1.3437	-0.1123	0.6365	0.5949
93	5	2.2	45	1.0002	1.12374	-0.12354	0.4644	0.5358
94	6	2.2	45	0.9192	0.90379	0.01541	0.4123	0.5069
95	7	2.2	45	0.7759	0.68383	0.09207	0.3958	0.3801
96	8	2.2	45	0.7693	0.46387	0.30543	0.3906	0.3787