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Predictive Corrosion-Inhibition Model for Mild Steel in Sulphuric Acid (H_2SO_4) by Leaf-Pastes of Sida Acuta Plant

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Abstract: The study of the corrosion inhibition of mild steel in sulphuric acid (H_2SO_4) by the leaf pastes of Sida Acuta was probed using the weight-loss technique. The highest inhibition efficiency of 91.46% with a reduction in corrosion rate from 3.1338mg.cm^{-2}.h^{-1} to 0.2825mg.cm^{-2}.h^{-1} was achieved by the addition of the leaf pastes of Sida Acuta at 30g per litre of 1.2M H_2SO_4. The prediction obtained using the artificial neural network gave the least error and was closer to the experimental corrosion rate value in comparison with the prediction by multiple regression.

Keywords: Corrosion Rate, Leaf-Pastes of Sida Acuta, Artificial Neural Network, Multiple Regression, Mild Steel, Sulphuric Acid (H_2SO_4)

1. Introduction

Corrosion is the degradation of a metal or an alloy as a result of its interaction with the environment. Few metallurgical problems are economically more important than the prevention of metallic corrosion; in Great Britain alone, it was estimated that the cost of metallic corrosion was up to 3% of the annual gross national product which is equivalent to £10 billion per capita [1]. The ultimate consequence of corrosion is the reversion of the metal to the ore from which it was produced. However, corrosion can be prevented by employing different methods such as coating, painting, addition of inhibitors and proper materials selection and design. This present work is concerned with the addition of inhibitors.

The toxicity of the known effective synthetic inhibitors has necessitated the search for alternative inhibitors that are not only effective but less expensive and ecologically friendly. These qualities have been found in plants. The use of plant extracts has demonstrated some considerable capacity to inhibit the corrosion of carbon steel in different acidic media [2-8]. In this study, we present the use of leaf pastes of Sida Acuta to inhibit the sulphuric acid-induced corrosion of mild steel. The phytochemical analysis of Sida Acuta's leaves as reported by [9] reveals the presence of alkaloid, phytate, saponin, flavonoid and tannin. These natural constituents may be responsible for adsorbing on the surface of the steel thereby effecting corrosion inhibition. The principal objectives of this research are to:

i. Investigate the efficacy of the leaf-pastes of Sida Acuta to inhibit the corrosion of mild steel in sulphuric acid solution,
ii. Develop a predictive corrosion rate model, and to
iii. Analyse the corrosion products with Fourier Transform Infrared (FTIR) spectroscopy.

Sida Acuta is a species of flowering plant in the mallow family, malvaceae. The plant is believed to have originated in Central America, but today has a pan-tropical distribution and is considered a weed in some areas [10]. Although native to Central America, *Sida Acuta* has spread throughout the tropics [11], including the major continental areas and a large portion of the oceanic islands. *Sida Acuta* is thought to have been introduced to northern Australia in the nineteenth century by Chinese prospectors who employed its fibres to make brooms [12]. However, much of the history and introduction and spread of this fairly inconspicuous plant has not been documented. In many areas, such as the Galapagos Islands, the species has been naturalized long enough to become well integrated into the local ecosystems [13].

Experimental values can be predicted by evaluating the relationship that exists between the dependent variable and some independent variable parameters. Multiple regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to the observed data [14]. On the other hand, the artificial neural network (ANN) is the computer simulation of a brain-like system of interconnected processing units (which are analogous to neurons) and are presumed to operate in parallel [15].

2. Methods

2.1. Preparation of Leaf-Pastes

Sida Acuta's fresh leaves were obtained within the University (Federal University of Technology Owerri, Nigeria) surrounding and thoroughly pounded using a manual blender to obtain the leaf-pastes. The leaf-pastes were added to the corrodent at 15g per litre, 30g per litre and 45g per litre of 0.7M, 1.2M and 2.2M H_2SO_4.

2.2. Fabrication of Mild Steel Coupons

A foot shear cutting machine was used to press cut mild steel ((wt%) C=0.20%, Zn=0.75%, Ti=0.28, Mn=0.23%, S=0.04%, P=0.035% and Fe balance) coupons of *40mm x 40mm* dimensions from a flat sheet metal of *1.5mm* thickness.

2.3. Weight-Loss Analysis

The experimental set up was made under aerated condition wherein the mild steel coupons were first abraded with coarse and fine emery papers and treated with acetone. The initial weights of the coupons were obtained using the Ohaus weighing balance before immersion into different study environments. The steel coupons were immersed in a plastic bowl containing the acid solution in the presence of the leaf-pastes of Sida Acuta at 15g per litre, 30g per litre and 45g per litre of 0.7M, 1.2M and 2.2M H_2SO_4. Another experimental set-up which did not contain any inhibitor was made for the purpose of comparison.

The following formulae were used in computing the rate at which the mild steel coupon corroded and the inhibition efficiency occasioned by the addition of the leaf-pastes of Sida Acuta:

$$CR\ (mg.cm^{-2}.h^{-1}) = (w_o - w_1)/A*t \quad (1)$$

$$I.E.\ (\%) = ((CR_{blank} - CR_{inhibitor})/ CR_{blank})*100 \quad (2)$$

Where,

CR = Corrosion rate.

I.E. = Inhibition efficiency.

CR_{blank} *= Corrosion rate of mild steel in the blank solution.*

$CR_{inhibitor}$ *= Corrosion rate of mild steel in the presence of an inhibitor.*

w_o *= Initial weight of coupon.*

w_1 *= Weight of coupon after immersion.*

2.4. Development of Predictive Model

2.4.1. Multiple Regression

Multiple regression is an extension of the simple regression technique. In multiple regression, prediction is made by comparing the dependent variable with two or more independent variables. In principle, multiple regression is expressed thus [16]:

$$Y^* = a + b_1X_1 + b_2X_2 + \ldots + b_nX_n \quad (3)$$

Where,

Y= The predicted value of Y (which is the dependent variable).*

a = The 'Y intercept'.

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*.*

X_1 *= An X score on your 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.*

X_n *= An X score on your* n^{th} *independent variable for which you are trying to predict a value of Y.*

Equation (3) can be made clearer to suit the present study wherein the experimental corrosion rate (*$mg.cm^{-2}.h^{-1}$*) is predicted by evaluating its relationship with some independent variables namely: quantity of leaf-pastes (g), concentration of acid (M), and time of exposure (h):

$$CR_{exp} = p_o + Q_1(\text{time}) + Q_2(\text{conc. of acid}) + Q_3(\text{quantity of leaf-pastes}) \quad (4)$$

Where,

CR_{exp} *= Experimental corrosion rate.*

p_o *= Regression intercept.*

Q_1 *= Slope of CR with respect to time of exposure.*

Q_2 *= Slope of CR with respect to conc. of acid.*

Q_3 *= Slope of CR with respect to quantity of leaf-pastes.*

2.4.2. Artificial Neural Network (ANN)

A neural network can be thought of as a network of "neurons" organised in layers. The predictors (or inputs) form the bottom layer, and the forecasts (or outputs) form the top layer. There may be intermediate layers containing "hidden neurons". Artificial neural networks are forecasting methods that are based on simple mathematical models of the brain. They allow complex nonlinear relationships between the response variable and its predictors [17]. In artificial neural network, the processing unit computes every signal that is sent to it. In addition, the processing unit not only sends a signal to other processors in the network but, applies an activation function to every signal to figure out a particular level of internal activity [15].

According to [17], the very simplest networks contain no hidden layers and are equivalent to linear regression. The coefficients attached to these predictors are called "weights". However, the forecasts are obtained by a linear combination of the inputs. The weights are selected in the neural network framework using a "learning algorithm". Once an intermediate layer with hidden neurons, is added, the neural network becomes non-linear. This is known as a multilayer feed-forward network where each layer of nodes receives inputs from the previous layers. The output of a node in one layer is an input to the next layer. The input to each node is combined using a weighted linear combination. Nevertheless, the result is then modified by a nonlinear function before obtaining the output. The schematic representation of the neuron is shown in Figure 1.

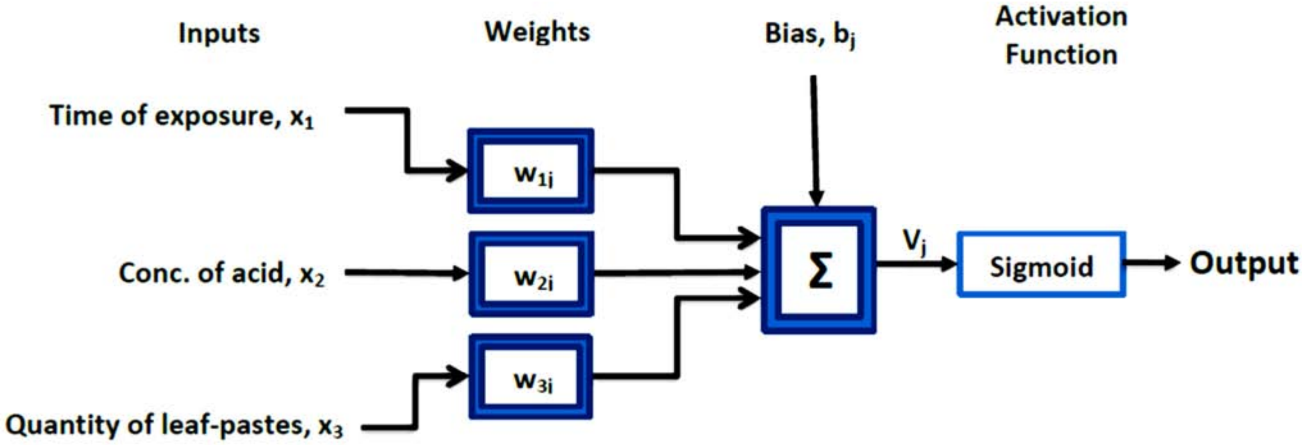


Figure 1. *Schematic representation of the neuron.*

The inputs of Figure 1 are linearly added to give:

$$V_j = b_j + \sum(x_i w_{ij}) \quad (5)$$

In the hidden layer, equation (5) is then modified using a nonlinear function called sigmoid to give:

$$S(V) = 1/(1+e^{-V_j}) \quad (6)$$

Where,
S (V) = Activation function.
V_j = Net input.
b_j = Bias of the unit.
w_{ij} = Weight of the unit.

2.4.3. Accuracy in Prediction

The Mean Square Error (MSE) and the Mean Absolute Error (MAE) are used to investigate how far the predicted value is to the real value. Mathematically, their equations are stated thus:

$$MAE = (1/N)\sum(C_i - D_i) \quad (7)$$

$$MSE = (1/N)\sum(C_i - D_i)^2 \quad (8)$$

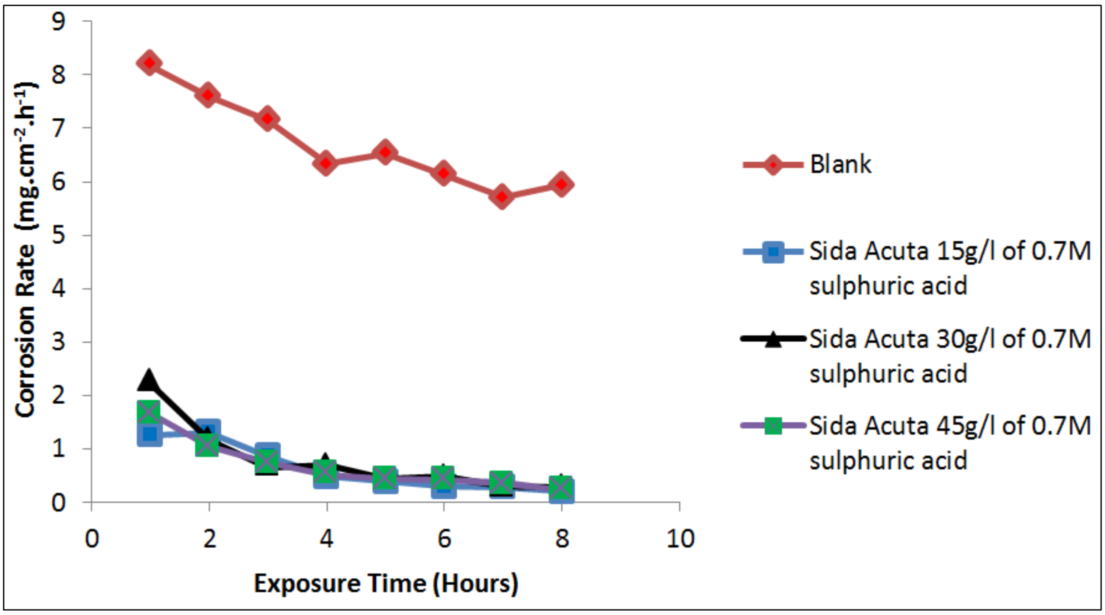
Where,
C_i = Predicted value.
D_i = Experimental value.
N = Number of samples considered.

3. Results

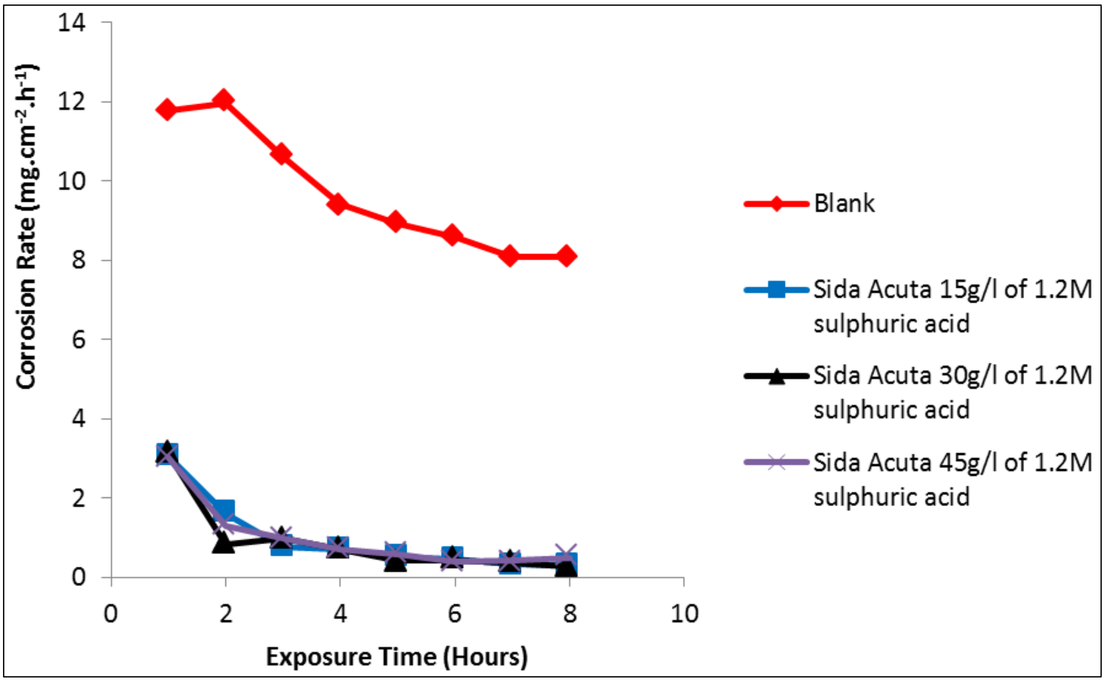
Table 1. *Effect of Addition of the Leaf-pastes of Sida Acuta on the Corrosion of Mild Steel Coupons Immersed in Sulphuric Acid Solution.*

Exposure Time (h)	0.7M H_2SO_4		1.2M H_2SO_4		2.2M H_2SO_4	
	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 leaf-pastes of Sida Acuta at 15g/l of H_2SO_4						
1	1.2663	89.52	3.0612	73.99	6.5783	81.40
2	1.3011	82.86	1.6163	86.50	4.4088	84.17
3	0.8713	87.83	0.7648	92.78	3.3225	86.08
4	0.4865	92.31	0.7108	92.45	2.7076	86.84
5	0.4078	93.76	0.5251	94.11	2.0882	89.25
6	0.3030	95.06	0.4603	94.64	1.6685	90.64
7	0.2743	95.19	0.3448	95.74	1.2650	90.49
8	0.2157	96.37	0.3002	96.28	1.2558	91.97
Average	0.6408	90.99	0.9729	90.81	2.9118	87.61
Addition of leaf-pastes of Sida Acuta at 30g/l of H_2SO_4						
1	2.2421	72.60	3.1338	73.38	6.2094	82.45
2	1.1748	84.52	0.8379	93.00	3.3748	87.88
3	0.6641	90.72	0.9904	90.65	1.9624	91.78
4	0.6883	89.12	0.7043	92.51	1.6642	91.91
5	0.4374	93.31	0.4200	95.29	1.7350	91.07
6	0.4865	92.06	0.4337	94.95	1.4851	91.67
7	0.3008	94.73	0.3738	95.38	0.9032	94.64

Exposure Time (h)	0.7M H_2SO_4		1.2M H_2SO_4		2.2M H_2SO_4	
	CR ($mg.cm^{-2}.h^{-1}$)	I.E (%)	CR ($mg.cm^{-2}.h^{-1}$)	I.E (%)	CR ($mg.cm^{-2}.h^{-1}$)	I.E (%)
8	0.2934	95.06	0.2825	96.50	1.5389	90.16
Average	0.7859	89.02	0.8971	91.46	2.1866	90.20
Addition of leaf-pastes of Sida Acuta at 45g/l of H_2SO_4						
1	1.6671	79.62	3.0350	74.22	6.2298	82.39
2	1.0412	86.28	1.2953	89.18	3.2383	88.37
3	0.7367	89.71	0.9904	90.65	2.3099	90.32
4	0.5184	91.81	0.7014	92.55	1.7440	91.15
5	0.4374	93.31	0.5844	93.45	1.3075	93.27
6	0.4308	92.97	0.3902	95.46	1.0877	93.90
7	0.3643	93.61	0.4186	95.82	0.8688	94.84
8	0.2447	95.88	0.4905	93.93	0.7671	95.09
Average	0.6801	90.40	0.9882	90.66	2.1941	91.17



(a)



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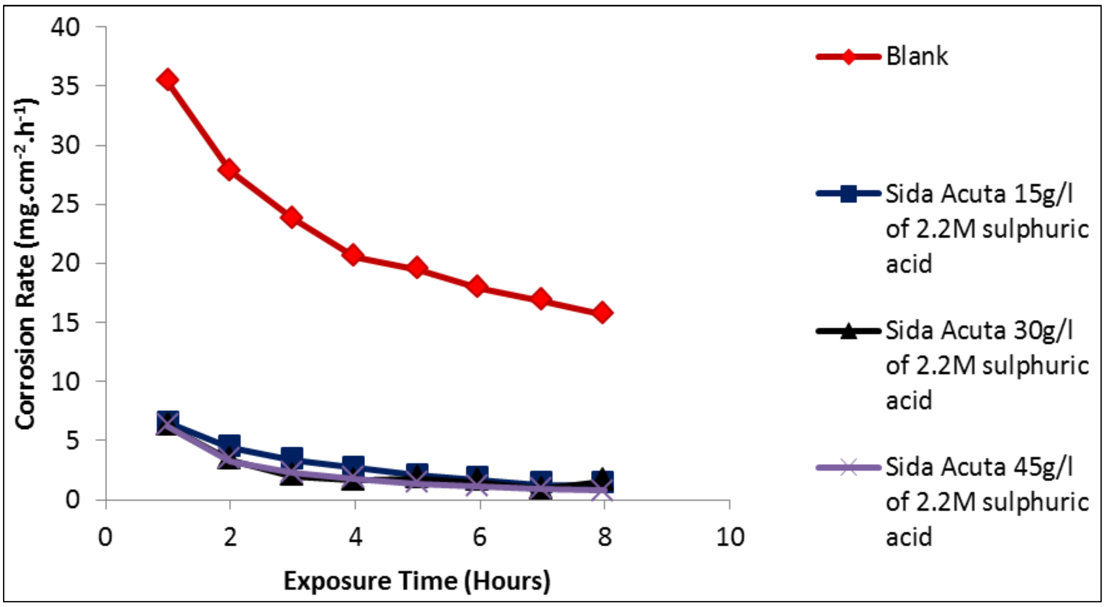
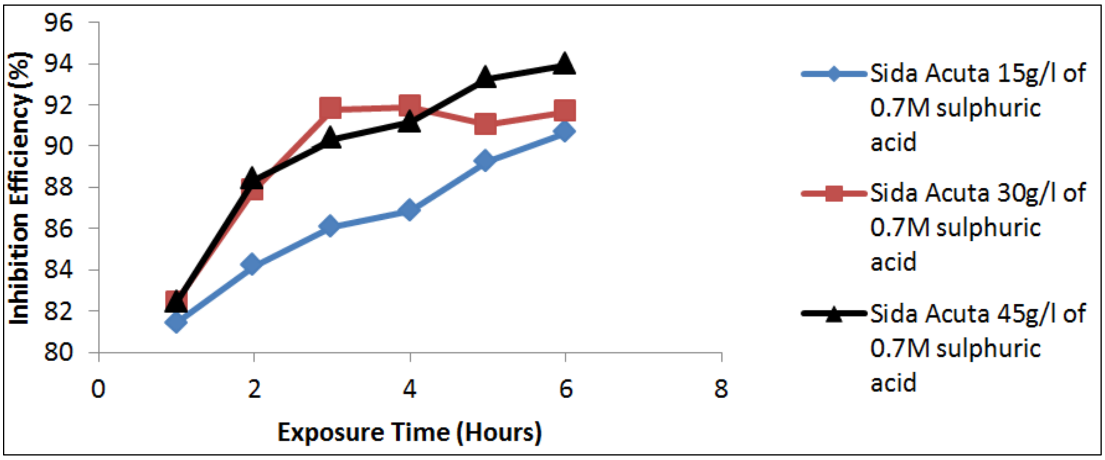
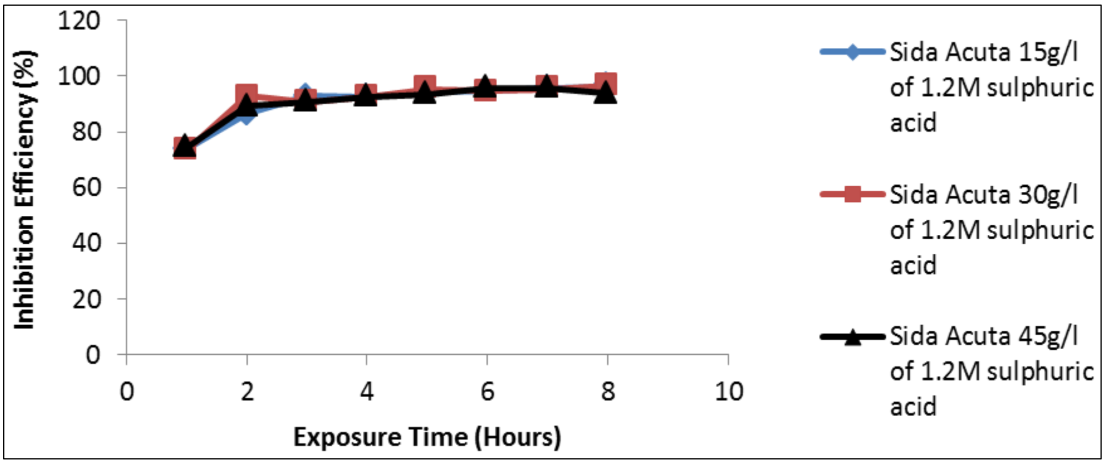


(c)

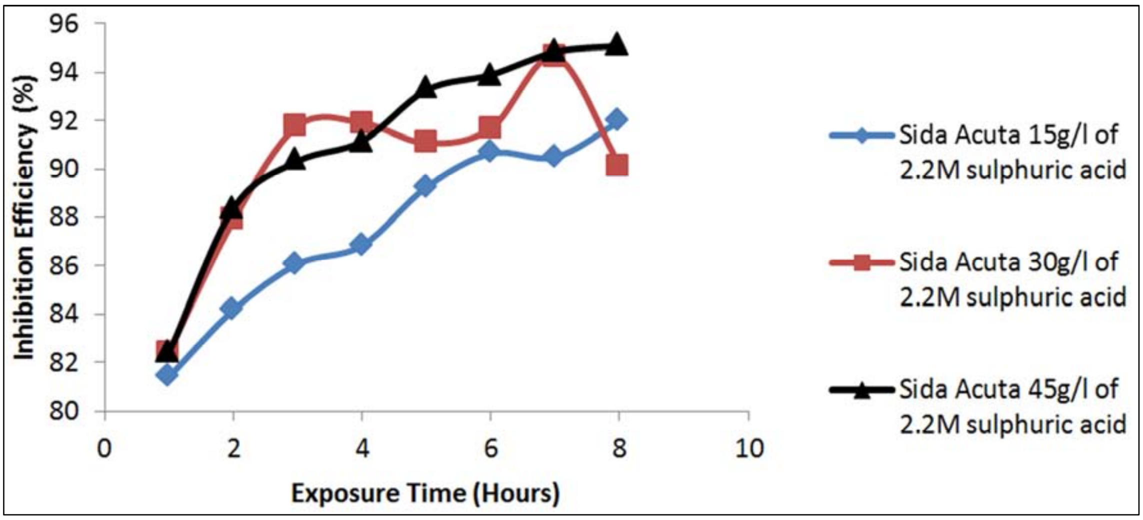
Figure 2. *Effect of addition of leaf-pastes of Sida Acuta on the corrosion of mild steel coupons immersed at: (a) 15g/l, 30g/l and 45g/l of 0.7M* H_2SO_4 *(b) 15g/l, 30g/l and 45g/l of 1.2M* H_2SO_4 *(c) 15g/l, 30g/l and 45g/l of 2.2M* H_2SO_4*.*



(a)



(b)



(c)

Figure 3. *Sida Acuta's corrosion inhibition efficiency for mild steel immersed at: (a) 15g/l, 30g/l and 45g/l of 0.7M H_2SO_4 (b) 15g/l, 30g/l and 45g/l of 1.2M H_2SO_4 (c) 15g/l, 30g/l and 45g/l of 2.2M H_2SO_4.*

Table 2. *Prediction of corrosion inhibition of mild steel in sulphuric acid medium by the leaf-pastes of Sida Acuta.*

Case	Time (h)	Conc_of_ H_2SO_4 (M)	Quantity_of_SA_ Leaf_ Pastes (g)	Exp. Corrosion Rate, CR (mg.cm^{-2}.h^{-1})	Prediction_by_MR		Prediction_by_ANN	
					CR	Error	CR	Error
1	1	0.7	0	8.1815	9.07701	-0.89551	7.8495	0.3320
2	2	0.7	0	7.5905	8.50764	-0.91714	7.0096	0.5809
3	3	0.7	0	7.1601	7.93827	-0.77817	6.5036	0.6565
4	4	0.7	0	6.3278	7.3689	-1.0411	6.1638	0.1640
5	5	0.7	0	6.5336	6.79953	-0.26593	5.9068	0.6268
6	6	0.7	0	6.1291	6.23016	-0.10106	5.6921	0.4370
7	7	0.7	0	5.7053	5.66079	0.04451	5.5003	0.2050
8	8	0.7	0	5.9448	5.09142	0.85338	5.3216	0.6232
9	1	0.7	15	1.2663	5.59205	-4.32575	0.813	0.4533
10	2	0.7	15	1.3011	5.02268	-3.72158	0.6945	0.6066
11	3	0.7	15	0.8713	4.45331	-3.58201	0.6369	0.2344
12	4	0.7	15	0.4865	3.88394	-3.39744	0.6077	-0.1212
13	5	0.7	15	0.4078	3.31457	-2.90677	0.5920	-0.1842
14	6	0.7	15	0.3030	2.74520	-2.4422	0.5827	-0.2797
15	7	0.7	15	0.2743	2.17583	-1.90153	0.5768	-0.3025
16	8	0.7	15	0.2157	1.60646	-1.39076	0.5724	-0.3567
17	1	0.7	30	2.2421	2.10710	0.13500	0.8332	1.4089
18	2	0.7	30	1.1748	1.53773	-0.36293	0.6455	0.5293
19	3	0.7	30	0.6641	0.96836	-0.30426	0.5576	0.1065
20	4	0.7	30	0.6883	0.39899	0.28931	0.5160	0.1723
21	5	0.7	30	0.4374	-0.17038	0.60778	0.4959	-0.0585
22	6	0.7	30	0.4865	-0.73975	1.22625	0.4860	0.0005
23	7	0.7	30	0.3008	-1.30912	1.60992	0.4811	-0.1803
24	8	0.7	30	0.2934	-1.87849	2.17189	0.4786	-0.1852
25	1	0.7	45	1.6671	-1.37786	3.04496	1.2557	0.4114
26	2	0.7	45	1.0412	-1.94723	2.98843	0.8490	0.1922
27	3	0.7	45	0.7367	-2.51660	3.25330	0.6504	0.0863
28	4	0.7	45	0.5184	-3.08597	3.60437	0.5573	-0.0389
29	5	0.7	45	0.4374	-3.65534	4.09274	0.5134	-0.076
30	6	0.7	45	0.4308	-4.22471	4.65551	0.4923	-0.0615
31	7	0.7	45	0.3643	-4.79408	5.15838	0.4820	-0.1177
32	8	0.7	45	0.2447	-5.36345	5.60815	0.4769	-0.2322
33	1	1.2	0	11.7710	10.87073	0.90027	14.2594	-2.4884
34	2	1.2	0	11.9760	10.30136	1.67464	11.9243	0.0517
35	3	1.2	0	10.5980	9.73199	0.86601	10.5678	0.0302
36	4	1.2	0	9.4100	9.16262	0.24738	9.7654	-0.3554
37	5	1.2	0	8.9209	8.59325	0.32765	9.2502	-0.3293
38	6	1.2	0	8.5939	8.02388	0.57002	8.8798	-0.2859
39	7	1.2	0	8.0869	7.45451	0.63239	8.5820	-0.4951

Case	Time (h)	Conc_of_ H_2SO_4 (M)	Quantity_of_SA_ Leaf_ Pastes (g)	Exp. Corrosion Rate, CR (mg.cm^{-2}.h^{-1})	Prediction_by_MR		Prediction_by_ANN	
					CR	Error	CR	Error
40	8	1.2	0	8.0791	6.88514	1.19396	8.3214	-0.2423
41	1	1.2	15	3.0612	7.38577	-4.32457	1.4246	1.6366
42	2	1.2	15	1.6163	6.81640	-5.20010	1.0145	0.6018
43	3	1.2	15	0.7648	6.24703	-5.48223	0.8198	-0.0550
44	4	1.2	15	0.7108	5.67766	-4.96686	0.7263	-0.0155
45	5	1.2	15	0.5251	5.10829	-4.58319	0.6793	-0.1542
46	6	1.2	15	0.4603	4.53893	-4.07863	0.6542	-0.1939
47	7	1.2	15	0.3448	3.96956	-3.62476	0.6396	-0.2948
48	8	1.2	15	0.3002	3.40019	-3.09999	0.6302	-0.3300
49	1	1.2	30	3.1338	3.90082	-0.76702	1.5140	1.6198
50	2	1.2	30	0.8379	3.33145	-2.49355	0.9874	-0.1495
51	3	1.2	30	0.9904	2.76208	-1.77168	0.7198	0.2706
52	4	1.2	30	0.7043	2.19271	-1.48841	0.5936	0.1107
53	5	1.2	30	0.4200	1.62334	-1.20334	0.5343	-0.1143
54	6	1.2	30	0.4337	1.05397	-0.62027	0.5058	-0.0721
55	7	1.2	30	0.3738	0.48460	-0.11080	0.4919	-0.1181
56	8	1.2	30	0.2825	-0.08477	0.36727	0.4851	-0.2026
57	1	1.2	45	3.0350	0.41586	2.61914	2.4023	0.6327
58	2	1.2	45	1.2953	-0.15351	1.44881	1.5488	-0.2535
59	3	1.2	45	0.9904	-0.72288	1.71328	1.0050	-0.0146
60	4	1.2	45	0.7014	-1.29225	1.99365	0.7247	-0.0233
61	5	1.2	45	0.5844	-1.86162	2.44602	0.5922	-0.0078
62	6	1.2	45	0.3902	-2.43099	2.82119	0.5300	-0.1398
63	7	1.2	45	0.4186	-3.00036	3.41896	0.5003	-0.0817
64	8	1.2	45	0.4905	-3.56973	4.06023	0.4860	0.0045
65	1	2.2	0	35.3757	14.45817	20.91753	30.6893	4.6864
66	2	2.2	0	27.8496	13.88880	13.96080	27.9154	-0.0658
67	3	2.2	0	23.8639	13.31943	10.54447	24.3414	-0.4775
68	4	2.2	0	20.5771	12.75006	7.82704	21.0607	-0.4836
69	5	2.2	0	19.4230	12.18069	7.24231	18.7407	0.6823
70	6	2.2	0	17.8311	11.61132	6.21978	17.3016	0.5295
71	7	2.2	0	16.8414	11.04195	5.79945	16.4286	0.4128
72	8	2.2	0	15.6365	10.47258	5.16392	15.8694	-0.2329
73	1	2.2	15	6.5783	10.97322	-4.39492	7.4228	-0.8445
74	2	2.2	15	4.4088	10.40385	-5.99505	5.1373	-0.7285
75	3	2.2	15	3.3225	9.83448	-6.51198	3.2185	0.1040
76	4	2.2	15	2.7076	9.26511	-6.55751	2.0324	0.6752
77	5	2.2	15	2.0882	8.69574	-6.60754	1.4281	0.6601
78	6	2.2	15	1.6685	8.12637	-6.45787	1.1382	0.5303
79	7	2.2	15	1.2650	7.55700	-6.29200	0.9962	0.2688
80	8	2.2	15	1.2558	6.98763	-5.73183	0.9224	0.3334
81	1	2.2	30	6.2094	7.48826	-1.27886	4.3190	1.8904
82	2	2.2	30	3.3748	6.91889	-3.54409	3.3949	-0.0201
83	3	2.2	30	1.9624	6.34952	-4.38712	2.3566	-0.3942
84	4	2.2	30	1.6642	5.78015	-4.11595	1.5038	0.1604
85	5	2.2	30	1.7350	5.21078	-3.47578	0.9840	0.7510
86	6	2.2	30	1.4851	4.64141	-3.15631	0.7221	0.7630
87	7	2.2	30	0.9032	4.07204	-3.16884	0.5988	0.3044
88	8	2.2	30	1.5389	3.50267	-1.96377	0.5407	0.9982
89	1	2.2	45	6.2298	4.00331	2.22649	4.7587	1.4711
90	2	2.2	45	3.2383	3.43394	-0.19564	4.1767	-0.9384
91	3	2.2	45	2.3099	2.86457	-0.55467	3.3241	-1.0142
92	4	2.2	45	1.7440	2.29520	-0.5512	2.3383	-0.5943
93	5	2.2	45	1.3075	1.72583	-0.41833	1.5022	-0.1947
94	6	2.2	45	1.0877	1.15646	-0.06876	0.9794	0.1083
95	7	2.2	45	0.8688	0.58709	0.28171	0.7126	0.1562
96	8	2.2	45	0.7671	0.01772	0.74938	0.5867	0.1804

Table 3. *Analysis for prediction of corrosion inhibition of mild steel by the leaf-pastes of Sida Acuta in sulphuric acid medium using multiple regression (MR).*

	Model Coefficients			
	Constant	Time (h)	Conc. of Acid (M)	Quantity of Leaf-pastes (g)
H_2SO_4	7.135	-0.569	3.587	-0.232

***Table 4.** Analysis for prediction of corrosion inhibition of mild steel by the leaf-pastes of Sida Acuta in sulphuric acid solution using artificial neural network (ANN).*

Independent variable importance for the addition of leaf-pastes of Sida Acuta in sulphuric acid				
		Importance		
Time		0.176		
Conc_of_H_2SO_4		0.250		
Quantity_of_Leaf-pastes		0.574		
Parameter estimates for the addition of leaf-pastes of Sida Acuta in sulphuric acid				
Predictor		Predicted Hidden Layer 1		Output Layer
		H(1:1)	H(1:2)	Exp_CR
Input Layer	(Bias)	3.680	-2.199	
	Time	0.058	-1.556	
	Conc_of_H_2SO_4	-0.492	1.290	
	Quantity_of_Leaf-pastes	3.334	0.865	
Hidden Layer 1	(Bias)			1.031
	H(1:1)			-5.872
	H(1:2)			3.103

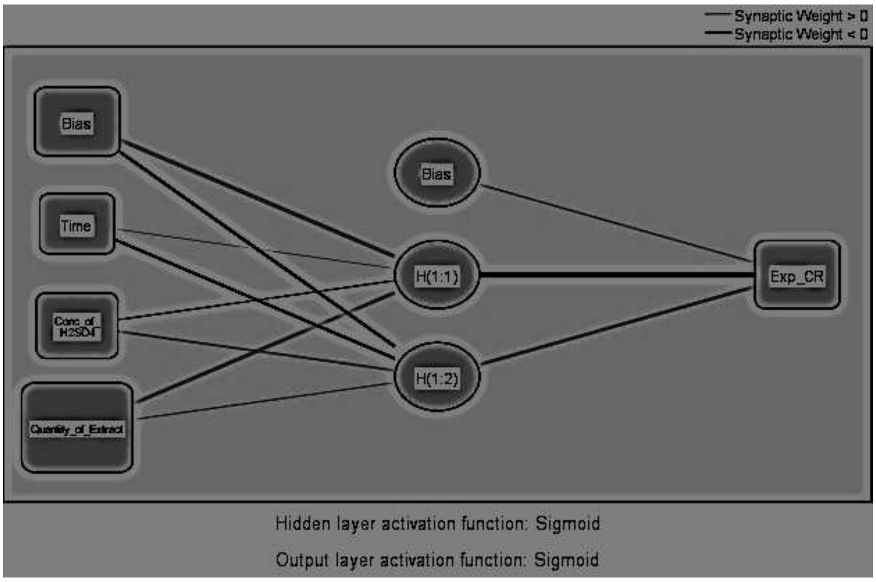


***Figure 4.** Artificial neural network for the prediction of corrosion inhibition of mild steel by the leaf-pastes of Sida Acuta.*

***Table 5.** Error analysis for the prediction of corrosion inhibition of mild steel by the leaf-pastes of Sida Acuta in sulphuric 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	3.097470316	0.448461458
Mean Squared Error	18.91703163	0.578227043

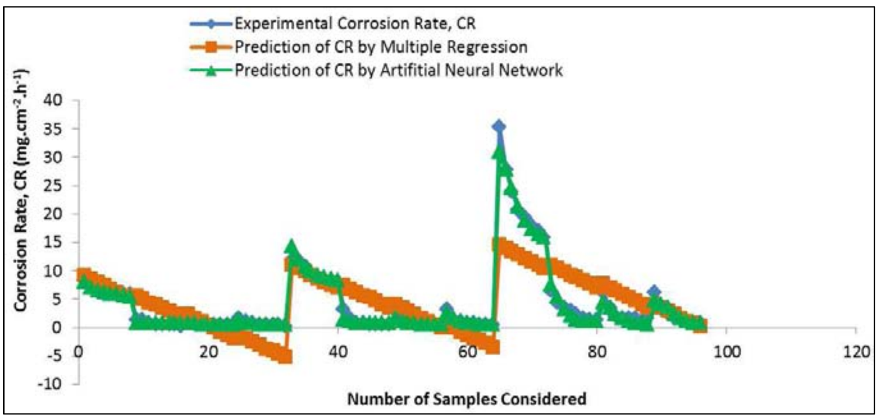


***Figure 5.** Comparison of error for the prediction of corrosion inhibition of mild steel by leaf-pastes of Sida Acuta in sulphuric acid using multiple regression, MR and artificial neural network, ANN.*

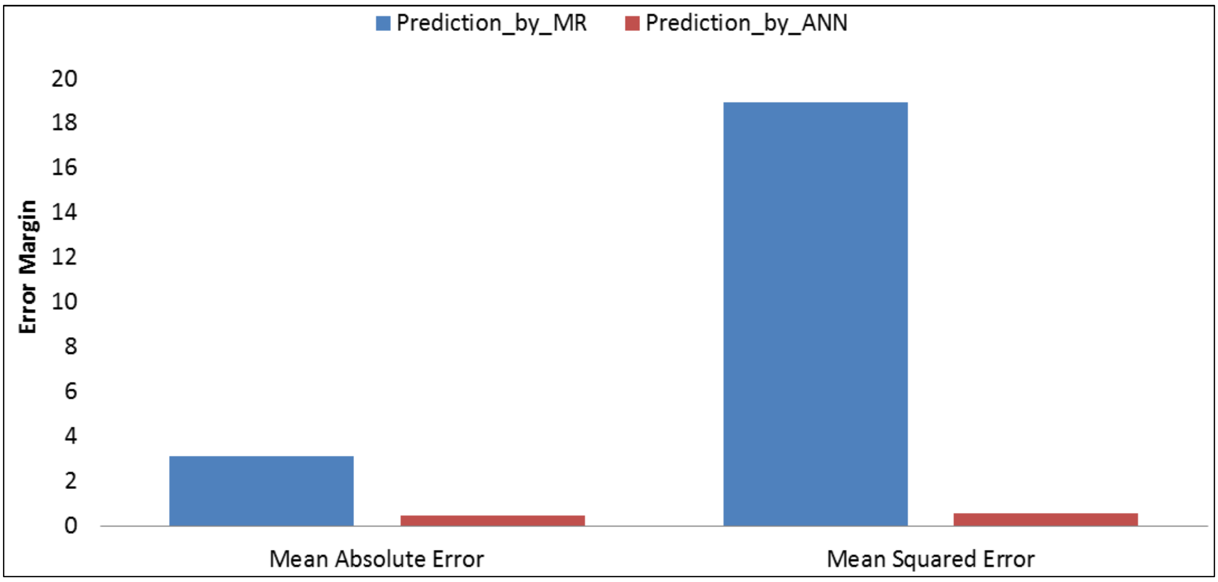


Figure 6. *Error graph for the prediction of corrosion inhibition of mild steel by Sida Acuta's leaf-pastes in sulphuric acid using multiple regression, MR and artificial neural network, ANN.*

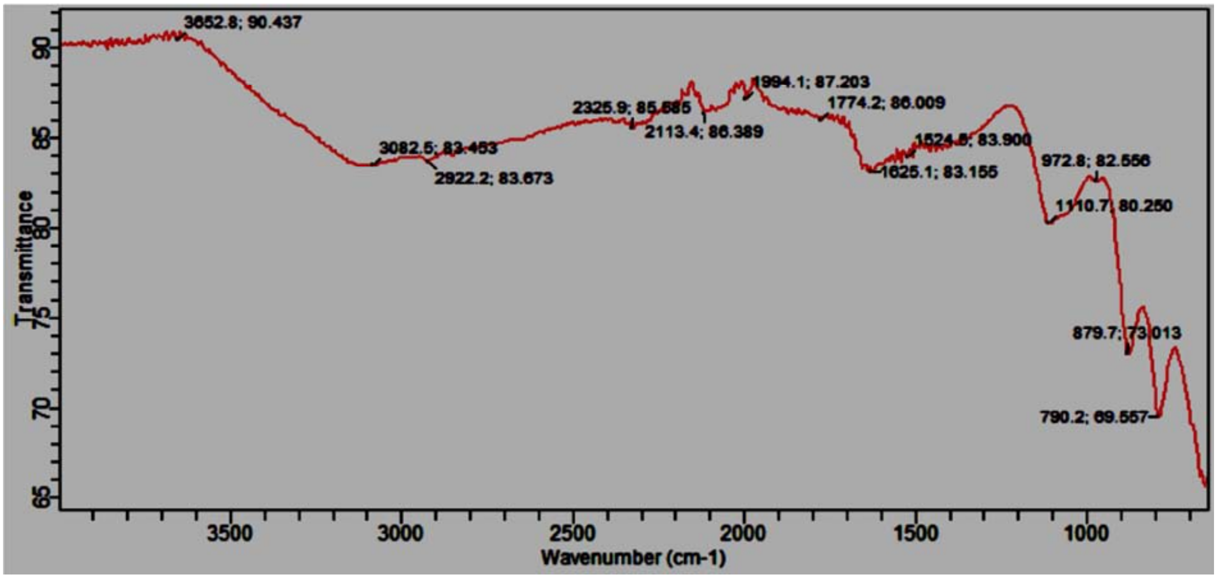


Figure 7. *FTIR spectrum of film on mild steel surface after immersion for eight hours in a medium containing the leaf-pastes of Sida Acuta at 30g per litre of 0.7M H_2SO_4.*

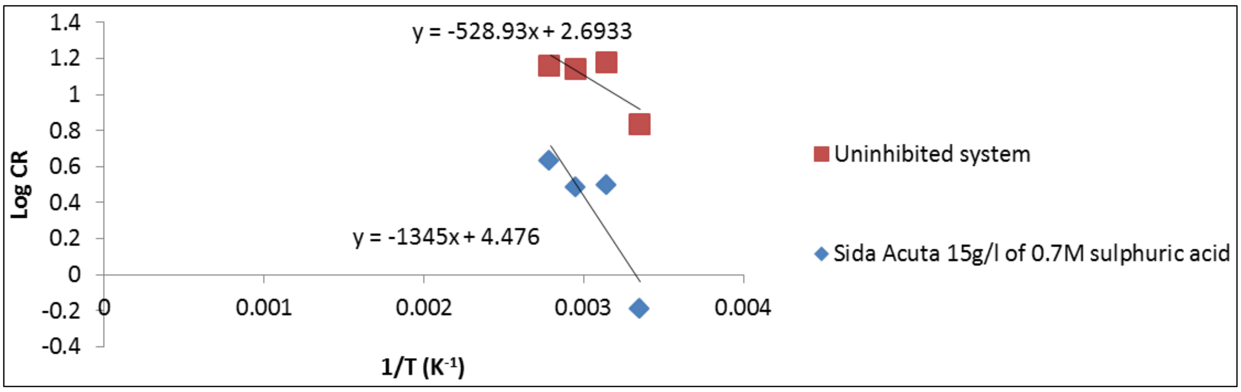


Figure 8. *Arrhenius plot for the effect of addition of the leaf-pastes of Sida Acuta to sulphuric acid induced corrosion of mild steel coupons immersed at 15g per litre of 0.7M H_2SO_4.*

***Table 6.** Effect of variation in temperature on the corrosion of mild steel coupons immersed in 0.7M H_2SO_4 without and with 15g of Sida Acuta's leaf-pastes.*

Temperature (K)	$CR_{SA\ addition}$ ($mg.cm^{-2}.h^{-1}$)	CR_{Blank} ($mg.cm^{-2}.h^{-1}$)	Log $CR_{SA\ addition}$	Log CR_{Blank}	1/T (K^{-1})
298	0.6408	6.6966	-0.1933	0.8259	0.003356
318	3.1007	14.9549	0.4915	1.1748	0.003145
338	3.0538	13.6092	0.4848	1.1338	0.002959
358	4.2676	14.3791	0.6302	1.1577	0.002793

$Slope_{Blank}$ = -528.9K^{-1}
Activation Energy, Q_{Blank} = 10,126.92J
$Slope_{SA\ addition}$ = -1345K^{-1}
Activation Energy, $Q_{SA\ addition}$ = 27,752.91J
$Slope_{SA\ addition}$ = Slope for the addition of the leaf-pastes of Sida Acuta at 15g/l of 0.7M acid concentration

4. Discussion of Results

4.1. Effect of Addition of the Leaf-pastes of Sida Acuta on the Corrosion of Mild Steel Coupons Immersed in Sulphuric Acid Medium

The addition of the leaf-pastes of Sida Acuta was observed to reduce the corrosion of mild steel coupons immersed in sulphuric acid solution. When the leaf-pastes of Sida Acuta were added at 15g per litre of 0.7M, 1.2M and 2.2M acid concentrations, the following average corrosion rate, CR and inhibition efficiency, I.E were obtained in the order $CR\ (I.E)$ as presented in Table 1: 0.6408$mg.cm^{-2}.h^{-1}$ (90.99%) in 0.7M H_2SO_4; 0.9729$mg.cm^{-2}.h^{-1}$ *(90.81%)* in 1.2M H_2SO_4 and 2.9118$mg.cm^{-2}.h^{-1}$ *(87.61%)* in 2.2M H_2SO_4. As the addition of the leaf-pastes was increased to 30g per litre of various acid concentrations, the average corrosion rate and inhibition efficiency were: 0.7859$mg.cm^{-2}.h^{-1}$ *(89.02%)* in 0.7M H_2SO_4; 0.8971$mg.cm^{-2}.h^{-1}$ *(91.46%)* in 1.2M H_2SO_4 and 2.1866$mg.cm^{-2}.h^{-1}$ *(90.20%)* in 2.2M H_2SO_4. Further addition of Sida Acuta's leaf-pastes at 45g per litre of 0.7M, 1.2M and 2.2M acid concentrations gave the following average corrosion rate and inhibition efficiency: 0.6801$mg.cm^{-2}.h^{-1}$ (90.40%) in 0.7M H_2SO_4; 0.9882$mg.cm^{-2}.h^{-1}$ (90.66%) in 1.2M H_2SO_4 and 2.1941$mg.cm^{-2}.h^{-1}$ (91.17%) in 2.2M H_2SO_4. The corrosion rate was observed to increase with increase in acid concentration. This development reveals that the corrosive environment becomes more aggressive as the concentration of acid is increased.

The corrosion rate-time curves for the mild steel coupons immersed in 0.7M, 1.2M and 2.2M H_2SO_4 with and without the leaf pastes of Sida Acuta are displayed in Figure 2. The corrosion rate of mild steel was observed to be lower in the presence of Sida Acuta's leaf-pastes than in the blank acid solution. Generally, the corrosion rate curves progressively decreased with time.

Figure 3 shows Sida Acuta's inhibition efficiency for mild steel immersed at 15g per litre, 30g per litre and 45g per litre of 0.7M, 1.2M and 2.2M H_2SO_4. The inhibition efficiency–time curve gradually increased with time. The highest inhibition efficiency of 91.46% with a corresponding reduction in corrosion rate from 3.1338$mg.cm^{-2}.h^{-1}$ to 0.2825$mg.cm^{-2}.h^{-1}$ was achieved by the addition of the leaf-pastes of Sida Acuta at 30g per litre of 1.2M H_2SO_4.

4.2. Prediction of Corrosion Inhibition of Mild Steel in Sulphuric Acid Solution by the Leaf-pastes of Sida Acuta

Multiple regression and artificial neural network were used to predict the corrosion rates of mild steel coupons in the presence and absence of the leaf pastes of Sida Acuta in sulphuric acid medium with the aid of the SPSS software. The predicted values are presented in Table 2. Using the multiple regression as illustrated in Table 3, the predictive equation for the corrosion inhibition of mild steel coupons by the leaf-pastes of Sida Acuta in sulphuric acid solution is stated thus:

$$CR_{SA\ in\ H_2SO_4 by\ MR} = 7.135 - 0.569\ (\text{time}) + 3.587\ (\text{conc. of acid}) - 0.232\ (\text{quantity of leaf} - \text{pastes}) \quad (9)$$

The prediction of the experimental corrosion rate of mild steel by the artificial neural network revealed the importance of the following independent variables; (exposure time (*h*), concentration of acid (*M*) and quantity of leaf pastes (*g*)) in the prediction of the dependent variable (Corrosion rate, *CR* ($mg.cm^{-2}.h^{-1}$)) for the addition of Sida Acuta's leaf-pastes to sulphuric acid medium as displayed in Figure 4 and presented in Table 4. The quantity of leaf pastes greatly influenced the prediction of the experimental corrosion rate by 57.4%, followed by concentration of acid, 25% and lastly the time of exposure, 17.6%.

The mean absolute error (MAE) and mean squared error (MSE) were used to figure out how close the predicted value was to the actual value. The two mean errors were computed using equation (7) and equation (8). The comparison of error results for the prediction of corrosion inhibition of mild steel by Sida Acuta's leaf pastes in sulphuric acid medium using multiple regression and artificial neural network are presented in Table 5 and displayed in Figures 5 and 6. The results show that the predictions by the artificial neural network did not just give minimal errors but were closer to the experimental corrosion rate values in comparison with the predictions by multiple regression.

4.3. FTIR Analysis of the Corrosion Inhibition of Mild Steel in H_2SO_4 by the Leaf-Pastes of Sida Acuta

Figure 7 shows the FTIR spectrum of the protective material that adhered on the surface of mild steel coupon owing to the addition of the leaf-pastes of Sida Acuta at 30g per litre of

0.7M H_2SO_4 for eight hours. The broad bands around the frequencies, 2922.2cm^{-1} and 3082.5cm^{-1} indicate the presence of C–H stretching of alkenes and aliphatic compounds. The variable band at 2113.4cm^{-1} reveals the presence of the triple carbon–carbon bond of alkynes. The C=O stretching of an acid anhydride is spotted around 1774.2cm^{-1}. Both conjugated and non-conjugated C=C stretching of alkenes are seen around the frequency, 1625.1cm^{-1}.

4.4. Effect of Variation in Temperature on the Corrosion of Mild Steel Coupons Immersed at 15g of Sida Acuta's Leaf-pastes per Litre of 0.7M H_2SO_4

The results of the variation in temperature between 298K and 358K on the corrosion of mild steel coupons without and with the addition of the leaf-pastes of Sida Acuta at 15g per litre of 0.7M H_2SO_4 are presented in Table 6 and shown in Figure 8. The activation energy, Q obtained for the uninhibited mild steel in 0.7M H_2SO_4 was 10,126.92J whilst in the presence of the leaf-pastes of Sida Acuta at 15g per litre of 0.7M H_2SO_4, higher activation energy of 27,752.91J was achieved. This higher value of activation energy obtained by the introduction of the leaf-pastes of Sida Acuta to the corrodent reveals that higher energy needs to be attained before further corrosion can take place.

5. Conclusion

The following summary can be drawn from the research:

i. The corrosion rate was observed to increase with increase in acid concentration. The corrosion rate of mild steel was observed to be lower in the presence of Sida Acuta's leaf-pastes than in the blank acid solution. Generally, the corrosion rate curves progressively decreased with time.
ii. The highest inhibition efficiency of 91.46% with a corresponding reduction in corrosion rate from 3.1338mg.cm^{-2}.h^{-1} to 0.2825mg.cm^{-2}.h^{-1} was achieved by the addition of the leaf-pastes of Sida Acuta at 30g per litre of 1.2M H_2SO_4.
iii. Predictions by the artificial neural network did not just give minimal errors but were closer to the experimental corrosion rate values in comparison with the predictions by multiple regression.
iv. The FTIR analysis of the corrosion product revealed the presence of C–H stretching of alkenes and aliphatic compounds, C=O stretching of an acid anhydride and conjugated and non-conjugated C=C stretching of alkenes.

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