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Prediction of Corrosion Inhibition Efficiency of *Acalypha godseffiana leaves* Extracts

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Abstract

As a follow up on our previous studies (Mathematical Modelling of Corrosion Inhibition Efficiency of Acalypha Wilkesiana Leaves**)** Acalypha godseffiana leaves were collected at Adeyemi College of Education, Ondo. Cleaned leaves were subjected to sun-dry and air-dry processes. Sun-dried and air-dried leaves were powdered, sieved and stored in desiccators at room temperature. A known mass of the powdered *leaves was soaked in ethanol in different containers for 72 hours to obtain inhibitor extracts. Extracts were used* as inhibitor for mild steel of known composition. Weight loss, inhibition efficiency (IE) and corrosion rate were studied using standard methods. Models that relate concentration of inhibitor, temperature to IE were proposed, established and evaluated using statistical methods. . The inhibition efficiency increases with increasing extracts concentration to 88.43 % and 88.37 % at 333K of 1.0 g/l of extracts for the air and sun-dried extracts, respectively. CD, MSC, AIC and SC were in the range of 0.8794 to 0.9790, 2.1 to 4.1, 67.3 to 104.8 and 73.1 to 101.8 for both air and sun dried extracts.

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The table revealed that the best models for sun and air dried extracts were linear with interaction with MSC (3.6 and 4.1), AIC (73.1 and 64.3) and SC (76.1 and 67.3), respectively. The worst models for sun and air dried extracts were log-linear without interactions and non- linear without interaction with MSC (2.1 and 2.9) , AIC (101.8 and 86.6) , SC (104.8 and 89.6), respectively. The cost analysis revealed that it is economical to utilise plant leaves extract. It was concluded that these two extracts of the present study can serve as effective green corrosion inhibitors for mild steel in acidic media and further investigations to assess the corrosion morphology and to isolate and confirm the active phytochemicals responsible for the inhibition of mild steel corrosion in acidic media are required.

Keywords: Inhibition efficiency; weight loss measurement; Corrosion; Plant extracts; Mild steel; Statistical analysis.

1. Introduction

Iron and its alloys are widely used in engineering works such as constructions of overhead tanks, general and petroleum refineries equipment, pipes and valves. The main setback of using iron and alloys of iron is its aggressive reactions in acidic media. Acid media are generally used in the removal of unwanted scale and rust on iron and its alloys in many industrial processes [1]. The environmental consequence of corrosion is enormous and its inhibition has been deeply investigated. Acids are commonly used in various engineering and important processes in industry, in pickling baths, in the extraction and processing of oil and gas and in other chemical and petrochemical industries in the technical cracking of petroleum, acids appear as a result of hydrolysis of salts and may have a destructive effect on the equipment as corrosion. Corrosion in mild steel is important and expensive problem in the industries and it represents a significant portion of loss as a result of lost production, inefficient operation, and high maintenance [2, 3]. It has been reported that one of the best methods of protecting metals against corrosion involves the use of inhibitors which are substances that slow down the rate of corrosion [2, 3]. This finding indicates that development of corrosion inhibitors based on organic compounds containing nitrogen, oxygen atoms is of growing interest in the field of corrosion and industrial applications [2, 3]. The corrosion inhibition is a surface process, which involves adsorption of the organic compounds on the metal surface. With reference to effects of chemical and synthetic inhibitors on the environment, there exists the need to develop a new class of corrosion inhibitors with low toxicity, good efficiency and model of factors that influence performance of the inhibitors. Investigation of natural products of plant origin as inexpensive and environmental friendly corrosion inhibitors is an indispensable research. Apart from environmentally friendly and ecologically acceptable, plant products are cheap, readily available and are renewable sources of materials [4]. The extracts from their leaves, barks, seeds, fruits and roots comprise mixtures of organic compounds containing nitrogen, sulphur, and oxygen atoms and some essential elements [4]. It has been reported that some plants function as effective inhibitors of selected metal corrosion in different aggressive environments [4]. It has been shown that plant materials, such oputia extract, *Telferia occidentalis* extract, limonene, *Prosopis cineraria*, zallouh root, olives leaves, *Datura stramonium*, *Gossipium hirsutum* extract Nicotiana tabacum extract and Phyllantus amarus extract are effective inhibitors for metal in aggressive solutions [4, 5]. Obi-Egbedi and his colleagues [4] has recently reported on the corrosion inhibitive effectiveness of metals by *Dacroydes edulis, Pachylobus edulis, Vigna unguiculata*, Gum Arabic, *Raphia hookeri and Ipomoea* *invulcrata*. Despite the high availability and many varieties of plant materials, only relatively few (nearly 300,000 plant species that exist on the earth, less than 1%, Al-Otaibi and his colleagues [5] have been thoroughly investigated and reports on the detailed mathematical models of the inhibition efficiencies are still scarce. More on corrosion and corrosion inhibitors can be found in literature such as Yaro [6 , 7], Khadom and Abdul- Hadi [8], Sanjay and his colleagues [9], Alaneme and his colleagues [10], Khadom and his colleagues [11], Ghulamullah and his colleagues [12], Hassan and his colleagues [13], Fouda and his colleagues [14], Nathiya and Vairamuthu [15]. The present study focuses on the broadening application of plant extracts of Acalypha godseffiana leaves for metallic corrosion control and reports on mathematical models of the inhibiting effect of extracts of Acalypha godseffiana leaves on mild steel corrosion in acidic medium.

2. Materials and method

The leaves of *Acalypha godseffiana* were collected at Adeyemi College of Education, Ondo ($07^0$04'24.6"N, $004^0$49'26.1"E and elevation 256.2 m) Ondo State, Nigeria. The leaves were rinsed with distilled water to reduce necessary impurities to the lowest level. Cleaned leaves were subjected to sun-dry and air-dry processes. Initial and final moisture contents of the leaves (air and sun dried) were determined using standard methods [16, 17]. Percentage moisture content (%) was computed as follows:

$$M_c = 100\left(\frac{W_1 - W_2}{W_1}\right) \tag{1}$$

Where; M_c is the moisture content (%), W_1 and W_2 are the initial and final weight of the leaves. A known mass (2 kg) of these sun-dried and air-dried leaves were powdered, sieved using British Standard sieve size and stored in desiccators at room temperature. A known mass of the powdered leaves was then soaked in ethanol in different containers for 72 hours to obtain inhibitor from ethanol extracts. These ethanol extracts were concentrated using rotary evaporator and finally evaporated to dryness using a water bath [16 ,17]. Solid residue extracts without ethanol were obtained. The obtained solid residue was used to prepare different concentrations (0.2 – 1.0 g/l) of inhibitors at intervals of 0.2. It should be noted that the study is limited to ethanol extracts of *Acalypha godseffiana* leaves. Commercial iron alloys (mild-steel) was purchased from commercial centre in Akure, Nigeria. Its chemical compositions were determined using Standard methods at the Mechanical Engineering Department of Federal University of Technology Akure, Ondo state, Nigeria. These alloys were cut into 18 x 16 x 4 mm, polished with emery papers (400 – 1000 grades), washed with distilled water, degreased with absolute ethanol and dried with acetone before storage in desiccators. Prepared iron alloys were subjected to acidic media of 2.0 M HCl solution with various concentrations (0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 g/l) of ethanol extracts of Acalypha godseffiana leaves as inhibitor at various temperature to ascertain effects of temperature on the performance of the inhibitor, of HCl was selected based on literature, Alaneme and his colleagues [10], Khadom and his colleagues [11], Ghulamullah and his colleagues [12], Hassan and his colleagues [13], Fouda and his colleagues [14], Nathiya and Vairamuthu [15]. Mass loss and Inhibition Efficiency (IE) were computed as follows:

$$CR = \frac{\Delta w}{AT} \quad (2)$$

Where; Δw is the weight loss (g), A is the surface area of the mild steel and T is the exposure time of the mild steel

$$IE(\%) = 100\left(\frac{CR_0 - CR_1}{CR_0}\right) \quad (3)$$

CR_0 is the corrosion rate of the mild steel in the absence of inhibitor (blank) and CR_1 is the corrosion rate of mild steel in the presence of inhibitor

A general mathematical model (Linear, interaction and polynomial) that relates IE, temperature and concentration of the inhibitor was proposed. Constants in the model were determined using MES method. These models were selected based on literature such as Anees and his colleagues [1], Alaneme and his colleagues [10], Khadom and his colleagues [11], Ghulamullah and his colleagues [12], Hassan and his colleagues [13], Fouda and his colleagues [14], Nathiya and Vairamuthu [15]. The models were evaluated statistically (Akaike Information Criterion, (AIC), Schwartz Criterion (SC), coefficient of Determination (CD) and Model of Selection Criterion (MSC)) using expected IE as reference data). The model equations are as follows:

Linear model: $IE = A + bX_1 + CX_2$ (4)

Where; IE is the inhibition efficiency (%), X_i is the concentration of extract, X_2 is the temperature of the solution and A, b, c and d are model's constants.

Linear with interaction: $IE = A + bX_1 + CX_2 + dX_1X_2$ (5)

Polynomial: Non-linear; $IE = AX_1^bX_2^c$ (6)

Linear: $Log(IE) = Log(A) + bLog(X_1) + cLog(X_2)$ (7)

Polynomial with interaction: Non-linear: $IE = AX_1^bX_2^c(X_1X_2)^d$ (8)

Linear: $Log(IE) = Log(A) + bLog(X_1) + cLog(X_2) + dLog(X_1X_2)$ (9)

Procedures employed in the computations of model constants using Microsoft Excel Solver (MES) are as follows:

a) Microsoft Excel Solver was added in on the toolbar of Microsoft Excel;
b) Target (limit) value of the iteration was set for the software based on square of difference as;

$$\sum_{i=1}^{n}\left(IE \quad - \quad \left(A+bX_1+CX_2\right)\right)^2 \tag{10}$$

c) Changing cells of the iterations were selected, number of iterations, degree of accuracy and maximum time for the iteration were set for the software to meet the target; and

d) The iteration started through Microsoft Excel Solver (Figure 1).

More on MES can be found in literature such as Oke and his colleagues [18 , 19], Barati [20]; Tay and his colleagues [21] and Hui and his colleagues [22]. The Model of Selection Criterion (MSC) is interpreted as the proportion of expected weight of the mild steel and observed weight of the mild steel variation that can be explained by the obtained weight of the mild steel. Higher value of MSC indicates higher accuracy, validity and the good fitness of the method. MSC was computed using equation (11) as follows:

$$MSC \quad = \quad \ln \frac{\sum_{i=1}^{n}\left(Y_{obsi} - \overline{Y}_{obs}\right)^2}{\sum_{i=1}^{n}\left(Y_{obsi} - Y_{cali}\right)^2} - \frac{2p}{n} \tag{11}$$

where, Y_{obsi} is the observed weight of the mild steel; $\overline{Y}_{obs}$ is the average of observed weight of the mild steel; p is the total number of fixed parameters to be estimated in the equation; n is the total number of concentration, and Y_{cali} is the expected weight of the mild steel. The Information Criterion of Akaike (AIC) was derived from the Information Criterion of Akaike [23]. It allows a direct comparison among models with a different number of parameters. The AIC presents the information on a given set of parameter estimates by relating the coefficient of determination to the number of parameters. The AIC values were computed using equation (12) as follows:

$$AIC \quad = \quad n\left(\ln \sum_{i=1}^{n}\left(Y_{obsi} - Y_{cali}\right)^2\right) \quad + \quad 2p \tag{12}$$

The Schwartz Criterion (SC) is defined by the formula in equation (13). SC was computed as follows:

$$SC \quad = \quad n\ln\left(\sum_{i=1}^{n}\left(Y_{obsi} - Y_{cali}\right)^2\right) \quad + \quad p\ln(n) \tag{13}$$

The more appropriate model is the one with the smaller SC value. Coefficient of determination (CD) can be interpreted as the proportion of expected data variation that can be explained by the obtained data. Higher values of CD indicate higher accuracy, validity and good fitness of the method. CD can be expressed as follows:

$$CD \quad = \quad \frac{\sum_{i=1}^{n}\left(Y_{obsi} - \overline{Y_{cali}}\right)^2 - \sum_{i=1}^{n}\left(Y_{obsi} - Y_{cali}\right)^2}{\sum_{i=1}^{n}\left(Y_{obsi} - \overline{Y_{cali}}\right)^2} \tag{14}$$

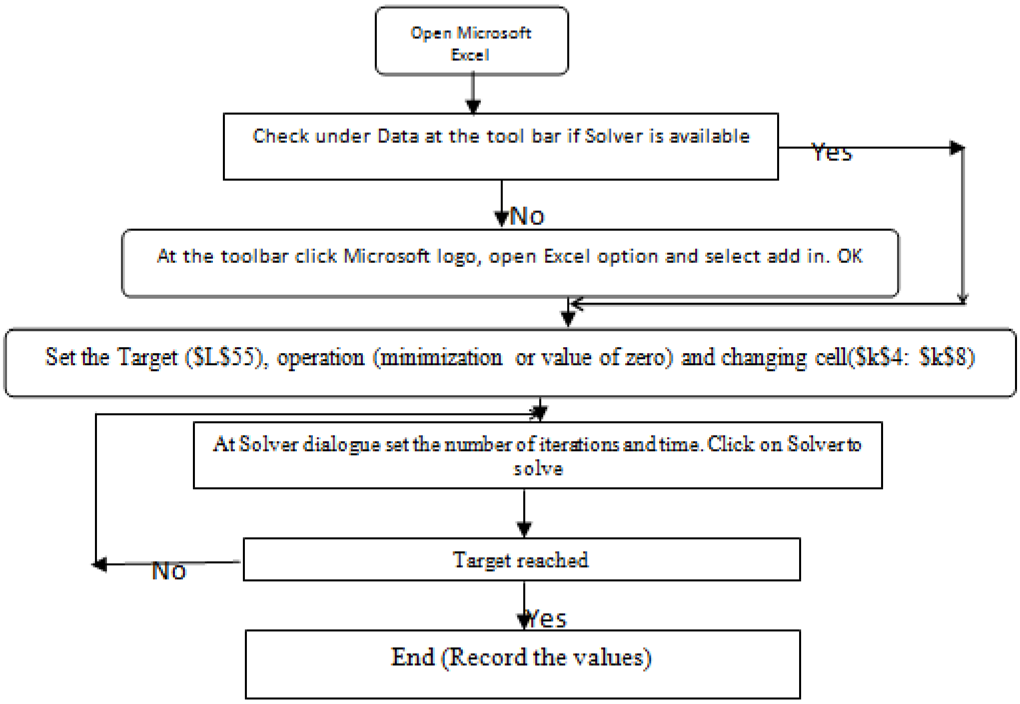

Figure 1: Flow chart of Microsoft Excel Solver in the computation of the constants in the model

Cost analysis of the extracts and two similar chemical inhibitors (carboxyl Benotriazole and 1, 2, 3 – Benotrizole) were conducted through market survey in Ondo State, Nigeria.

3. Results and discussion

Umoren and his colleagues [24] stated that the weight loss techniques as scientific assessment have found broad practical application in corrosion evaluations. The rate of corrosion can be defined as the ratio of the loss in weight of the mild steel to its area and the time length over which the evaluation was conducted. A major advantage of this technique is its relative simplicity and availability. In addition, the technique uses a direct parameter for the quantitative evaluation of corrosion (the loss in weight of the mild steel). The weight loss and corrosion rate obtained for the corrosion behaviour of mild steel in 2.0 M HCl solution containing leaves extracts of *Acalypha godseffiana* within the concentration range of 0.2 to 1.0 g/L are presented in Figures 2 and 3, respectively.

Figure 2 shows the weight loss–time curves for mild steel in 2 M HCl without and with different concentrations of leaves of *Acalypha godseffiana* extract (air and sun dried) at different temperatures. Similar Figure for the corrosion rate of the leaves extract (air and sun dried) are depicted in Figures 3 and 4 at the various temperature and at room temperature, respectively. It is seen from the Figures that the amount of material loss decreases significantly in the presence of the extracts compared to the blank acid solution and was also found to be dependent on the concentration of the extracts (air and sun dried). This indicates that the additives inhibit the corrosion of mild steel in 2 M HCl solution. Also the amount of mild steel loss increases with increase in temperature and greater loss in mass of the mild steel specimen was recorded at 333 K both in the absence and presence of the studied leaves extracts. The values of corrosion rate in the absence and presence of different extract concentrations are presented in Figure 3. Results in the Figure indicate that the extracts (air and sun dried) act as good corrosion inhibitor for mild steel in 2 M HCl solution given that the corrosion rate was reduced in the presence of the extracts (air and sun dried) compared to their absence.

Further assessment of Figure reveals that corrosion rate increases with increase in temperature with the highest values obtained at 333K for all the systems investigated. Figures 5 and 6 present inhibition efficiencies of the extracts (air and sun dried). The inhibition efficiency increases with increasing extracts concentration and is more pronounced for the air-dried compared to the sun-dried extract.

The inhibition efficiency values of 88.43 % and 88.37 % were observed at 333K of 1.0 g/l of extracts each. Evaluation of the Figures reveals an increasing trend in inhibition efficiency with increasing experimental temperatures for all the system studied. This observation suggests possible adsorption of some of the phytochemicals on the metal surface at higher temperatures. Such behaviour shows that the additives were chemically adsorbed on the metal surface. In a similar study, Al-Otaibi and his colleagues [5] observed maximum inhibition efficiency for alcoholic extract of *Artemisia sieberi*. and *Tripleurospermum auriculatum* (90.9%) followed by *Carthamus tinctorius*. (89.0%), *Lycium shawii*. (85.4%), and *Ochradenus baccatus* (84.7%) suggesting that these plant extracts could serve as effective green corrosion inhibitors.. In order to check the stability of plant extracts in the acidic media, inhibition efficiency (IE %) was measured for some of the plant extracts present in the acidic medium at different time intervals by Al-Otaibi and his colleagues [5].

The inhibition efficiency (IE %) values for plant extract in acidic medium at different time intervals were also studied and are given. It was clear that the observed inhibition efficiency (IE %) remain unchanged with time and the plant extracts are unaffected by their presence in the acid solution suggesting that plant extracts are stable in 0.5 M HCl media. It was reported that the corrosion of mild steel in HCl solution containing plant extracts can be inhibited due to the adsorption of phytochemicals present in plant extracts through their lone pair of electrons and p-electrons with the d-orbitals on the mild steel surface [5].

The polar functions with S, O or N and p-electrons of the organic compounds are usually regarded as the reaction center for the establishment of the adsorption process. It is a known fact that adsorption of the inhibitors is the main process affecting the corrosion rate of metals. Inhibition adsorption can affect the corrosion rate in two possible ways [5].

In first way, inhibitors decrease the available reaction area through adsorption on the metal which is called geometric blocking effect. In second way, inhibitors modify the activation energy of the cathodic and/or anodic reactions occurring in the inhibitor-free metal in the course of the inhibited corrosion process which is called energy effect.

It is a difficult task to determine which aspects of the inhibiting effect are connected to the geometric blocking action and which are connected to the energy effect.

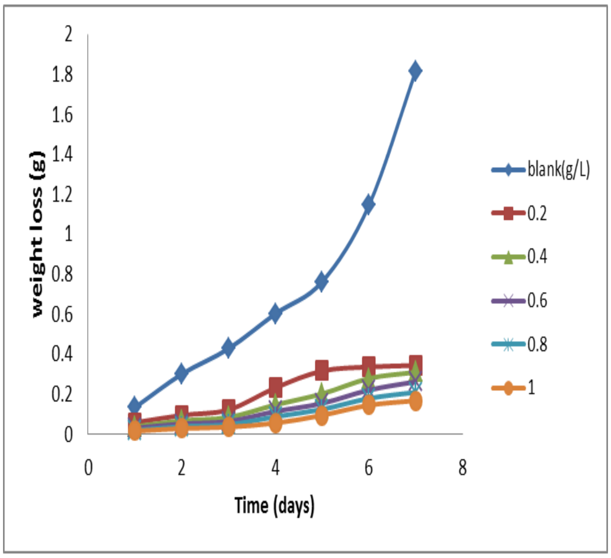

Figure 2a: Weight loss of the mild steel in sun-dried leaves *Acalypha godseffiana* extract

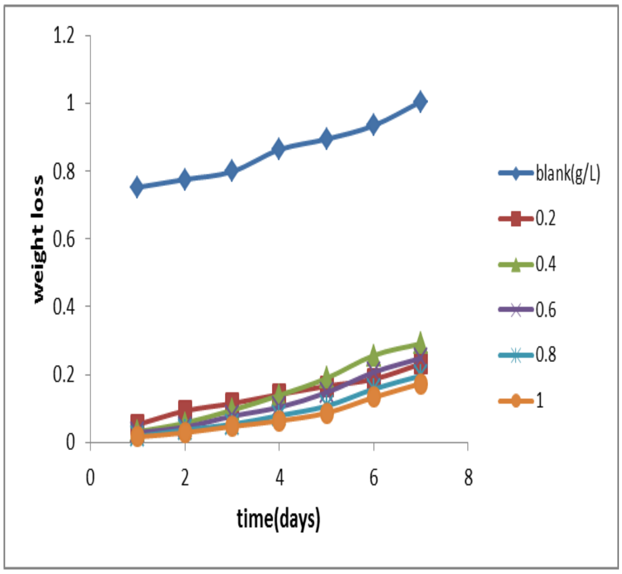

Figure 2b: Weight loss of the mild steel in air-dried leaves *Acalypha godseffiana* extract

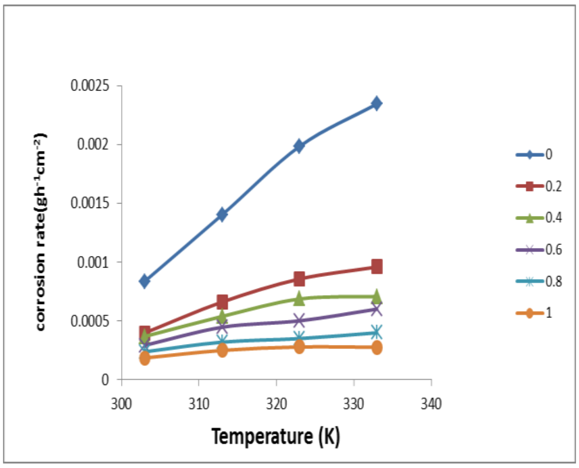

Figure 3a: Corrosion rate of the mild steel in sun-dried leaves *Acalypha godseffiana* extract

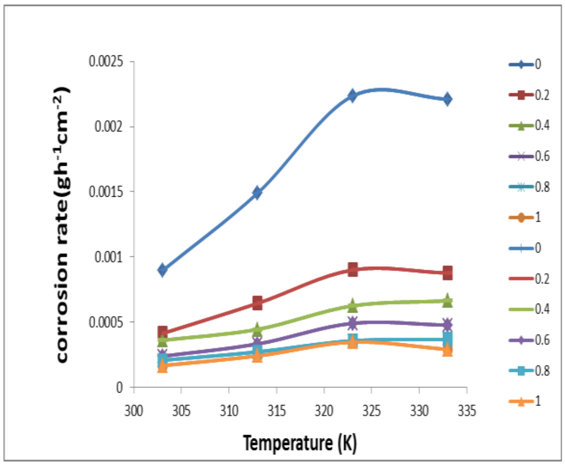

Figure 3b: Corrosion rates of the mild steel in air-dried leaves *Acalypha godseffiana* extract

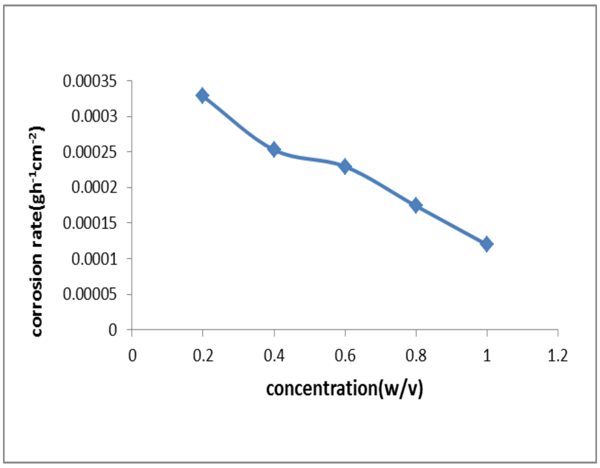

Figure 4a: Corrosion rate of the mild steel in sun-dried leaves *Acalypha godseffiana* extract at constant temperature

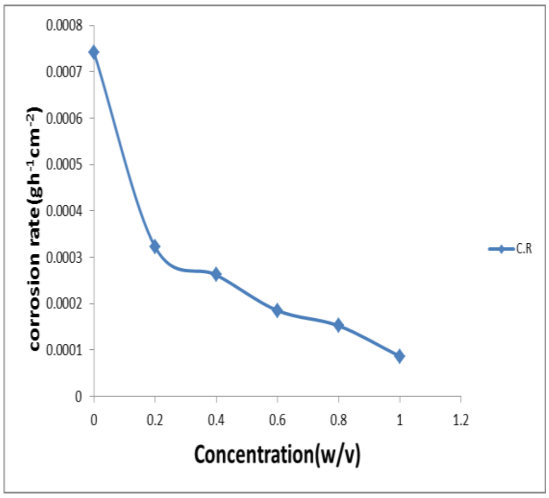

Figure 4b: Corrosion rate of the mild steel in air-dried leaves *Acalypha godseffiana* extract at constant temperature

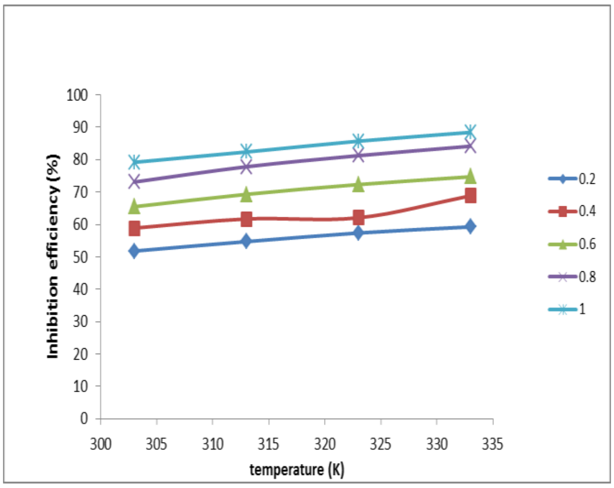

Figure 5a: Inhibition Efficiencies of sun-dried leaves *Acalypha godseffiana* extract

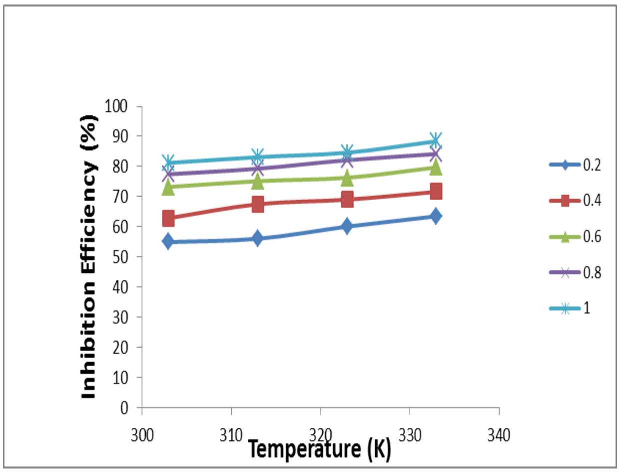

Figure 5b: Inhibition Efficiencies of air-dried leaves *Acalypha godseffiana* extract

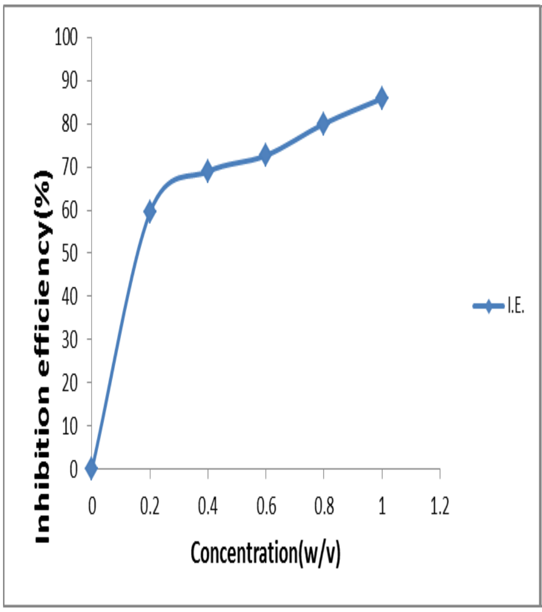

Figure 6a: Inhibition Efficiencies of sun-dried leaves *Acalypha godseffiana* extract at constant temperature

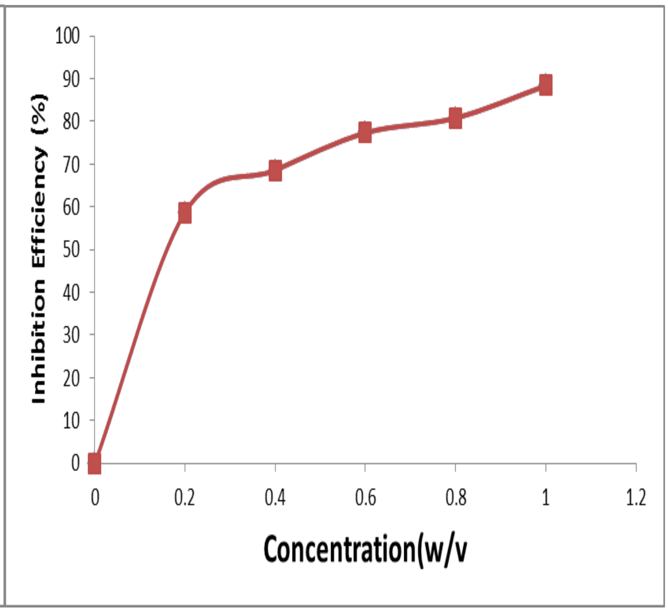

Figure 6b: Inhibition Efficiencies of air-dried leaves *Acalypha godseffiana* extract at constant temperature

Theoretically, no shifts in the corrosion potential should be observed after addition of the corrosion inhibitor if the geometric blocking effect is stronger than the energy effect. Al-Otaibi and his colleagues [5] documented that Gas chromatography–mass spectrometry (GC–MS) analysis of plant extracts led to the identification of 26 components from all the studied plants. It is interesting to see here that all the identified compounds from plant extracts contained oxygen and/or p-electrons in their molecules. Moreover, from the previous studies on the phytochemical constituents of the plant extracts it was established that the plant extracts used in this study also contain a mixture of organic compounds containing O, N or p-electrons in their molecules (Table 1). Hence, the corrosion inhibition of mild steel through these studied plants may be attributed to the adsorption of the phytochemicals containing O, N or p-electrons in their molecules as these atoms are regarded as centres of adsorption onto the metal surface. The highly complex chemical compositions of the plant extracts make it rather difficult to assign the inhibitive effect to a particular compound present in plants extracts. Having confirmed the corrosion inhibition effectiveness of these plants extracts, further detailed investigation for each plant extract through inhibitive assay guided isolation using surface analytical techniques will enable the characterization of the active compounds in the adsorbed layer and assist in identifying the most active phytochemicals.

Table 1: Quantitative Phytochemical Screening of the Extracts of Acalypha Godseffiana

	Sundried Acalypha godseffiana	**Airdried Acalypha godseffiana**
Saponin (mg/g)	22.54	26.54
Tannin (mg/g)	7.83	8.26
Phlobatannin (mg/g)	-	-
Flavonoid (mg/g)	5.41	8.24
Steroid (mg/g)	9.44	9.83
Terpenoid (mg/g)	7.36	11.14
Alkaloid (%)	-	-
Cardiac Glycoside (Legal test) (mg/g)	7.04	15.85

The model equations for the air dried inhibitor are as follows:

$$IE = -50.93 + 26.69X_1 + 0.336X_2 \tag{4}$$

$$IE = -9.83 - 41.78X_1 + 0.207X_2 - 0.215X_1X_2 \tag{5}$$

$$IE = 0.149X_1^{0.190}X_2^{1.493} \tag{6}$$

$$Log(IE) = -1.79 + 0.183Log(X_1) + 1.477Log(X_2) \tag{7}$$

$$IE = 0.160X_1^{0.186}X_2^{1.9775}\left(X_1X_2\right)^{0.003} \tag{8}$$

$$Log(IE) = -1.598 + 0.189Log(X_1) + 1.400Log(X_2) + 0.0003Log\left(X_1X_2\right) \tag{9}$$

The model equations for the sun dried inhibitor are as follows:

$$IE = -9.25 + 28.44X_1 + 0.124X_2 \tag{4}$$

$$IE = 31.29 - 7.74X_1 + 0.056X_2 + 0.114X_1X_2 \tag{5}$$

$$IE = 2.193X_1^{0.218}X_2^{0.614} \tag{6}$$

$$Log(IE) = 0.404 + 0.206Log(X_1) + 0.583Log(X_2) \tag{7}$$

$$IE = 2.057X_1^{0.188}X_2^{0.593}(X_1X_2)^{0.032} \tag{8}$$

$$Log(IE) = 0.789 + 0.217Log(X_1) + 0.434Log(X_2) + 0.0006Log(X_1X_2) \tag{9}$$

These linear equations revealed that there was a decrease (negative constants) in the amount of dissolved iron in the presence of the inhibitors (leaves extracts) compared to the blank solution. In the blank acid solution (2 M HCl) the concentration of dissolved Fe will be found to be 26.72 and 43.09 mg/L, 49.55 and 32.78 mg/l for linear and interaction equations, and for air and sun- dried respectively. It can be explained further that atoms of the metal are reduced and passed into the solution as ions. The amount of ions in the solution will increase with the concentration of the acid media and with temperature, in the absence of inhibiting species. Inhibitors are commonly used to reduce acid attack on the substrate metal and then, reduce the amount of metal ions being passed into the solution. The model equations (linear, non- linear and interactions) revealed that inhibition efficiencies depends more on the concentration of the inhibitor than the temperature of the solution. Hence the adsorption of ethanol extract of *Acalypha godseffiana* leaves on mild steel surface is consistent with the mechanism of chemical adsorption. Higher coefficient of concentration in IE model equation than temperature may be attributed to the adsorption of components of the extracts on the steel surface at lower temperature, producing a barrier, which isolates the surface from the corrosion environment. Table 2 presents detail of statistical evaluation of the model equations. From the table it was revealed that CD, MSC, AIC and SC were in the range of 0.8794 to 0.9790, 2.1 to 4.1, 67.3 to 104.8 and 73.1 to 101.8 for both air and sun dried extracts. The table revealed that the best models for sun and air dried extracts were linear with interaction with MSC (3.6 and 4.1), AIC (73.1 and 64.3) and SC (76.1 and 67.3), respectively. The worst models for sun and air dried extracts were log-linear without interactions and non- linear without interaction with MSC (2.1 and 2.9) , AIC (101.8 and 86.6) , SC (104.8 and 89.6), respectively.

Figure 7 presents relationship between calculated IE and experimental IE for all the models. The Figures revealed that there were good relationship between the two IEs .

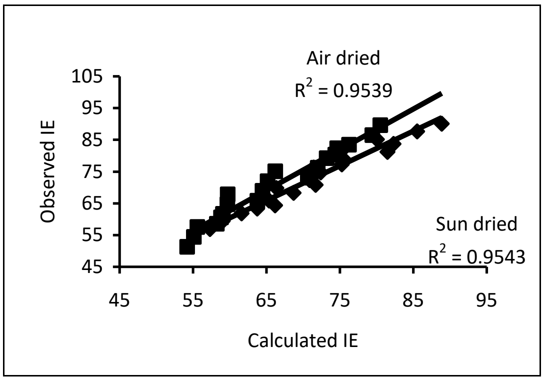

Figure 7a: Linear model without interaction

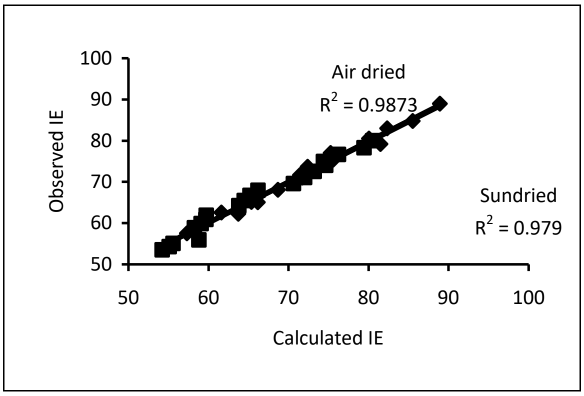

Figure 7b: Linear with Interaction model

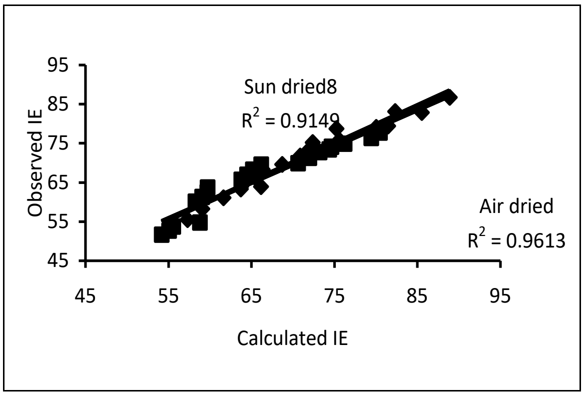

Figure 7c: Polynomial without interaction model

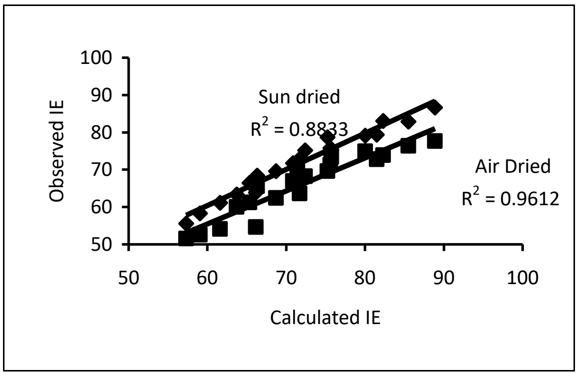

Figure 7d: Polynomial with interaction model

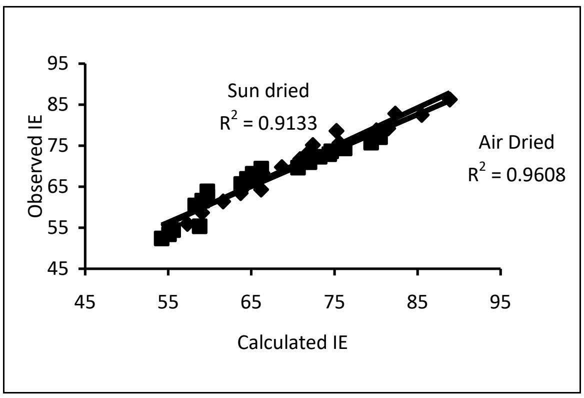

Figure 7e: Log- linear without interaction model

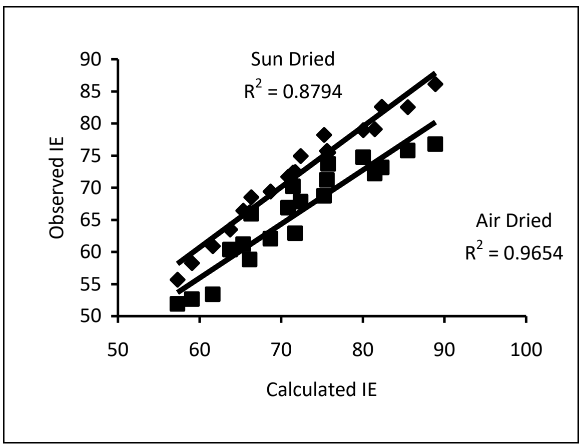

Figure 7f: Log-linear with interaction model

Table 2: Statistical evaluation of models

		Information Criterion of Akaike (AIC)	**Schwartz Criterion (SC)**	**Model of Selection Criterion (MSC)**	**CD**	
Linear equation	without interaction	72.4	75.4	3.7	0.9539	Air dried
		74.9	77.8	3.5	0.9543	Sun Dried
	with interaction	64.3	67.3	4.1	0.9873	Air dried
		73.1	76.1	3.6	0.9790	Sun Dried
Non- Linear equation	without interaction	86.6	89.6	2.9	0.9613	Air dried
		101.1	104.1	2.2	0.9149	Sun Dried
	with interaction	86.6	89.6	2.9	0.9612	Air dried
		101.1	104.1	2.2	0.8833	Sun Dried
Log-Linear equation	without interaction	87.0	90.0	2.9	0.9608	Air dried
		101.8	104.8	2.1	0.9133	Sun Dried
	with interaction	84.6	87.6	3.0	0.9654	Air dried
		97.8	100.8	2.3	0.8794	Sun Dried

3.1. Cost Analysis

In cost analysis, cost effective analysis approach was utilized while life cycle cost was not fully utilized. An inhibitor is cost-effective if, on the basis of life cycle cost analysis of competing alternatives, it is determined to have the lowest costs expressed in present value terms for a given amount of benefits. Cost-effectiveness analysis can also be used to compare inhibitors with identical costs but differing benefits. In this case, the decision criterion is the discounted present value of benefits. The alternative inhibitor with the largest benefits would normally be favoured. Life Cycle Costs are the total cost to an organization for acquisition and ownership of a product or asset over the life of the asset. For example, the life cycle cost of a school includes all of the future maintenance and repairs, as well as the initial construction and fixtures cost. This is sometimes referred to as capital costs plus operating costs, or one-time costs plus recurring costs. Any program should calculate life cycle costs. Figure 8 presents cost analysis of the three inhibitors. The figure revealed that both sun-dried and air-dried leaves of *Acalypha godseffiana* extract has the lowest cost compared with the other two extracts.

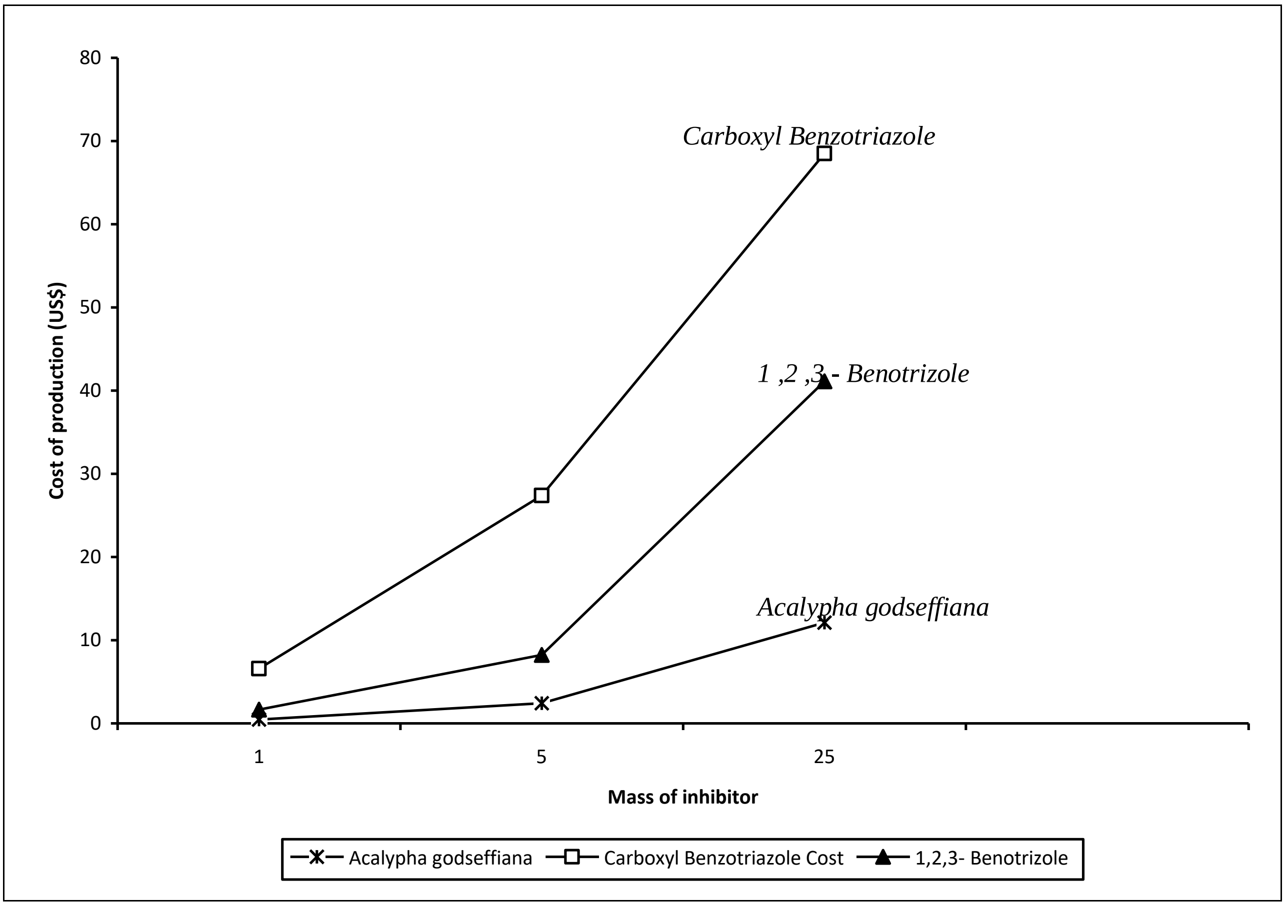

Figure 8: Cost analysis of the three inhibitors

4. Conclusion

The ethanol extracts of the sun-dried and air-dried leaves of *Acalypha godseffiana* extract have showed promising corrosion inhibition properties for mild steel in 2M HCl media. On comparing the percentage

inhibition efficiencies of these extracts with the blank, it can be concluded that:

a. The ethanol extracts of the sun-dried and air-dried leaves of *Acalypha godseffiana* revealed that the inhibition efficiency increases with increasing extracts concentration to 88.43 % and 88.37 % at 333K of 1.0 g/l of extracts for the air and sun-dried extracts, respectively.
b. The inhibition efficiency also increases with increasing temperature of the reaction system suggesting a chemical adsorption mechanism..
c. The best models for sun and air dried extracts were linear with interaction with MSC (3.6 and 4.1), AIC (73.1 and 64.3) and SC (76.1 and 67.3), respectively. The worst models for sun and air dried extracts were log-linear without interactions and non- linear without interaction with MSC (2.1 and 2.9) , AIC (101.8 and 86.6) , SC (104.8 and 89.6), respectively.

d. The cost analysis revealed that it is economical to utilise plant leaves extract. It was concluded that these two extracts of the present study can serve as effective green corrosion inhibitors for mild steel in acidic media.

5. Recommendations

Studies on *Acalypha godseffiana* leaves demonstrate that its extracts represent a major new initiative in corrosion inhibition with the advantages of low cost and high effectiveness, combined with absence of toxicity and polluting effects. From the results of this study, it can be recommended that ethanol extracts of *Acalypha godseffiana* could be used as an alternative green inhibitor for mild steel.

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