

1           **CORROSION INHIBITION OF ALUMINIUM IN ACIDIC MEDIUM BY**  
2           **DIFFERENT EXTRACTS OF *OCIMUM GRATISSIMUM***  
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20           **ABSTRACT**  
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**Aims:** This study is aimed at using plant extracts to prevent corrosion of aluminium in acidic medium. The inhibition efficiency of different extracts of 1M HCl, ethanol and distilled water were determined.

**Study design:** Gravimetric method was used for the analysis.

**Place and Duration of Study:** Department of Chemistry, Federal University of Technology, Owerri, Nigeria, between March and November, 2011.

**Methodology:** Aluminium sheets of AA1060 and purity 98.98% was used. Each sheet was mechanically press-cut into coupons of dimension 3 cm x 3 cm. The solvents used for extraction of *ocimum gratissimum* leaf were 1M HCl, ethanol and distilled water, respectively. A hole with diameter 0.5 cm was drilled in each aluminium coupon and suspended in beakers containing test solution using glass hook. The weight loss was determined by retrieving coupons from test solutions at intervals. The coupons were weighed after retrieving. The different in weight was taken as weight loss of aluminium.

**Results:** The percentage of inhibition efficiency(% I.E) was calculated at 303 K and 333 K, respectively. The result indicates that % I.E increases as concentration of inhibitor increases. The trend of inhibition efficiency were in order : Distilled H<sub>2</sub>O > C<sub>2</sub>H<sub>5</sub>OH > 1M HCl. The result indicates that increase in temperature decreases inhibition efficiency and degree of surface coverage. The result shows that apparent activation energy E<sub>a</sub>, increases as inhibitor concentration increases. The activation energy of distilled water extract range between 45.02 to 79.90 kJ/mol. While the

activation energies of ethanol and 1 M HCl extracts of the inhibitor ranges between 35.12 to 72.93 kJ/mol and 26.60 to 65.25 kJ/mol, respectively. The experimental data obtained corroborated with Langmuir and Flory Huggins adsorption isotherms. **Conclusion:** This study indicates that different extracts of *ocimum gratissimum* inhibits aluminium surface in presence of 1M HCl. The result of the analysis shows that inhibition efficiency and degree of surface coverage decreases as temperature increases. The activation energy of different extracts increases as concentration of inhibitor increases. The negative values of  $\Delta G_{ads}$  shows that adsorption of inhibitor on surface of aluminium is spontaneous.

*Keywords: Acid corrosion, weight loss, aluminium, adsorption, ocimum gratissimum.*

## 1. INTRODUCTION

Aluminium is a hard, strong, white metal. It is highly electropositive and resistant to corrosion because a hard, tough film of oxide is formed on the surface (Cotton and Wilkinson, 1972). The surface film is amphoteric, hence the metal could dissolve readily in both strong acid and alkaline media. Hydrochloric acid solutions are normally used for pickling of aluminium and electrochemical etching processes that normally lead to substantial loss of metal to corrosion. Aluminium is extensively used in industry as well as domestic applications.

Attempts have been made to reduce aluminium surface film dissolution and hence protect the metal in aggressive acid and alkaline media. Some of the methods employed to reduce corrosion of aluminium is application of sulphur, oxygen or nitrogen containing organic compounds as corrosion inhibitors to hinder corrosion reaction and thus reduce corrosion rate (Moussa et al; 1998; Madkour et al; 1999; Ebenso et al; 2001; Aytac et al; 2005). These organic compounds function by forming a protective adsorption layer on aluminium surface which isolates the corroding metal from action of corrodent.

Corrosion behaviour of aluminium have been studied in acid media. It has been reported that addition of halide salt to sulphuric acid solution containing organic inhibitor, effectively inhibits iron corrosion (Oguzie et al; 2004; Elewady et al; 2008). Halides have been reported to inhibit corrosion of some metals in strong acids and this effect depends on ionic size and charge.

The use of chemical inhibitors have been a concern about its toxicity which affects the living organism as well as poisoning of environment. The use of plant extracts to prevent corrosion have become important because they are environmentally acceptable, readily available and renewable source for a wide range of inhibitors. Plant extracts are rich source of naturally synthesized chemical compounds that can be extracted by simple methods with low cost (Abdel-Gaber et al; 2008). These

extracts are biodegradable and do not contain heavy metals or other toxic compounds. The use of plant extracts as corrosion inhibitor of metals in acidic and alkaline media have been reported (Abiola et al;2007; Kliskic et al 2000; Umoren and Ebenso,2008; Oguzie, 2005; Eddy and Ebenso, 2008).

*Ocimum gratissimum* (scent leaf) is widely distributed in tropical Africa especially Nigeria. It belongs to lamiacea family and most abundant of genus *Ocimum*. The Igbos of Eastern part of Nigeria call it Nchonwu. The Yorubas of Western part of Nigeria call it Efinrin ajase. Whereas Hausas of Northern part of Nigeria call it Daidoya (USDA, 2008). It is a perennial plant and woody at base. It has an average height of 1-3 m high and leaves are broad, narrowly ovate, usually 5-13 cm long and 3-9 cm wide. It is scented shrub with lime-green fuzzy leaves. It is used in Nigeria for nutritional and therapeutic purposes. In coastal area of Nigeria it is used for treatment of epilepsy, high fever and diarrhea, while in savannah areas, decoctions of its leaves are used to treat mental illness. The Igbos of Eastern Nigeria use *Ocimum gratissimum* for management of baby's cord by keeping the wound sterile. It is used as antifungal, antibacterial and for seasoning of foods.

## 2.0 MATERIALS AND METHOD

### 2.1 Material Preparation

Aluminium sheets of AAI060 and purity 98.98% were obtained from Material and Metallurgical Engineering Workshop, Federal University of Technology, Owerri, Nigeria. Each sheet was 0.1 cm in thickness and mechanically press-cut into coupons of dimension 3 cm x 3 cm. The coupons were descaled using wire brush and degreased in absolute ethanol, dried in acetone, weighed and stored in moisture- free desicator prior to use. The solvents used for extraction of *Ocimum gratissimum* leaf were 1 M HCl, ethanol and distilled water, respectively. All the solvents used in this study were of analytical reagent grade.

### 2.2 Extraction of plant

Sample leaves of *Ocimum gratissimum* were obtained from Ihiagwa market in Owerri, Imo State, Nigeria. The leaf samples were washed and dried under the sunlight and ground to fine powder. 10 g of leaf extract were extracted with soxhlet extractor for 3 hours using 1 M HCl, ethanol and distilled water, respectively. After extraction the samples were cooled and filtered. The filtrate obtained were used to prepare inhibitor concentrations between 20 mg/l and 100 mg/l in HCl corrodents.

## 2.3 Gravimetric method

In weight loss experiment, a hole with diameter 0.5 cm was drilled in each aluminium coupon so that it could hang freely in solution. The aluminium coupons were suspended in beakers containing 200 ml of test solution maintained at 303--333 K with glass hooks and rods in a thermo-stated water bath. The weight loss was determined by retrieving coupons from test solutions at 3 hours intervals. The coupons after retrieving from test solution were scrubbed with bristle brush under running water, dried in acetone and weighed (Ebenso et al;2001). The difference in weight was taken as weight loss of aluminium. From weight loss, the inhibition efficiency (%I.E) of extract and corrosion rate (CR) of aluminium were calculated using equations 1 and 2, respectively.

$$\% \text{ I.E} = (1 - w_2/w_1) \times 100 \dots \dots \dots (1)$$

$$\text{CR (gh}^{-1} \text{ cm}^{-2}) = \Delta w/AT \dots \dots \dots (2)$$

where  $w_1$ , and  $w_2$  are weight loss of aluminium in absence and presence of inhibitor, respectively. A is area of coupon in  $\text{cm}^2$ , T is period of immersion in hours and  $\Delta w = w_1 - w_2$ .

The degree of surface coverage was calculated using :

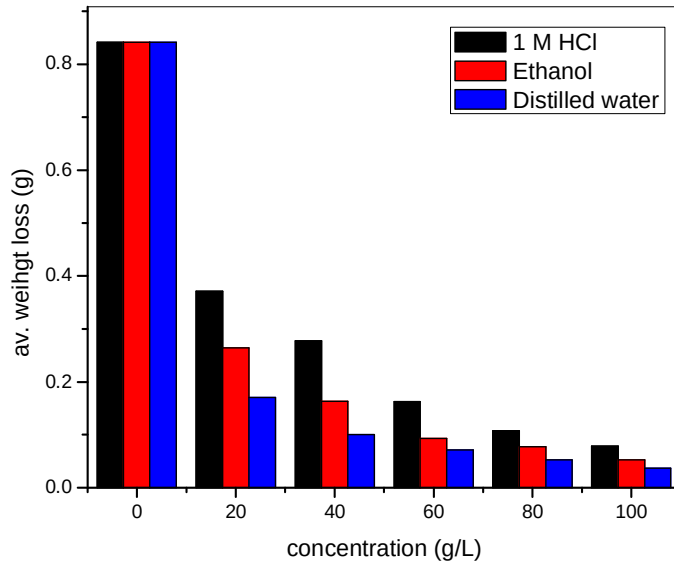
$$\Theta = 1 - [C_{\text{Rinh}}/C_{\text{RBC}}] \dots \dots \dots (3)$$

where  $\theta$  is surface coverage;  $C_{\text{Rinh}}$  is corrosion rate for aluminium in presence of inhibitor,  $C_{\text{RBC}}$  is corrosion rate for aluminium in the absence of inhibitor.

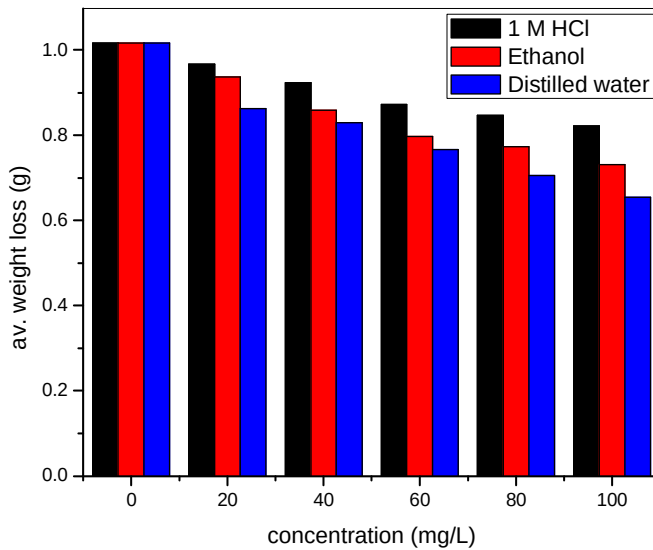
## 3.0 RESULTS AND DISCUSSION

### 3.1 Weight loss consideration

Figs. 1 and 2 represented data of weight loss against concentration for aluminium corrosion in 1M HCl in absence and presence of different concentrations of inhibitor, *Ocimum gratissimum* at 303 k and 333 k, respectively. As shown in Figs. 1 and 2, increase in concentration of inhibitor, decreases weight loss of aluminium samples. The result shows that weight loss of aluminium increases as temperature increases as depicted in Fig. 2. The decrease in weight loss as inhibitor concentration increases shows that components of inhibitor retards corrosion of Al samples. The reduction in weight loss of Al samples as inhibitor concentration increases may be attributed to adsorption of inhibitor on surface of Al and thereafter impede corrosion either by merely blocking reaction sites (anodic and cathodic) or by altering mechanism of anodic and cathodic processes. The result indicates that weight loss of Al sample using different extracts of inhibitor were in order : 1M HCl >  $\text{C}_2\text{H}_5\text{OH}$  > distilled  $\text{H}_2\text{O}$ .



127  
 128 Fig 1: Variation of weight loss of aluminium in HCl at various concentrations of  
 129 1 M HCl, ethanol and distilled water extracts of *Ocimum gratissimum* at 303  
 130 k



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 132 Fig 2. Variation of weight loss of aluminium in HCl at various concentrations of  
 133 1 M HCl, ethanol and distilled water extracts of *Ocimum gratissimum* at  
 134 333 K  
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### 3.2 Inhibition Efficiency and Surface Coverage.

The percentage of inhibition efficiency (% I.E) was calculated and represented in tables 1 and 2 at 303k and 333k, respectively. The result revealed that different extracts of inhibitor inhibits corrosion of Al sample in hydrochloric acid solution. The result indicates that % I.E increases as concentration of inhibitor increases. A parameter ( $\theta$ ), which represents part of metal surface covered by inhibitor molecules were calculated for different inhibitor concentrations and represented in tables 1 and 2. The result shows that surface coverage ( $\theta$ ) increases as inhibitor concentration increases. The increase in inhibition efficiency and surface coverage as concentration of extracts increases may be due to the presence of complex chemical composition of extracts. The increase in inhibition efficiency with increase in inhibitor concentration suggests that inhibitor molecule were adsorbed at aluminium sample /solution interface where adsorbed species mechanically screen the coated part of aluminium surface from action of corrosive medium.

**Table 1: Effect of various inhibitor extracts on % I.E and  $\theta$  for Al corrosion in 1M HCl at 303 k.**

| Concentration<br>mg/l | 1m HCl extract of<br><i>Ocimum gratissimum</i> | Ethanol extract of<br><i>Ocimum gratissimum</i> | Distilled water extract of<br><i>Ocimum gratissimum</i> |          |        |          |
|-----------------------|------------------------------------------------|-------------------------------------------------|---------------------------------------------------------|----------|--------|----------|
|                       | % I.E.                                         | $\theta$                                        | % I.E.                                                  | $\theta$ | % I.E. | $\theta$ |
| 20.00                 | 55.96                                          | 0.56                                            | 68.62                                                   | 0.69     | 79.79  | 0.80     |
| 40.00                 | 67.04                                          | 0.67                                            | 80.60                                                   | 0.81     | 88.11  | 0.88     |
| 60.00                 | 80.70                                          | 0.81                                            | 88.96                                                   | 0.89     | 91.53  | 0.92     |
| 80.00                 | 87.31                                          | 0.87                                            | 90.87                                                   | 0.91     | 93.80  | 0.94     |
| 100.00                | 90.72                                          | 0.91                                            | 93.74                                                   | 0.94     | 95.65  | 0.96     |

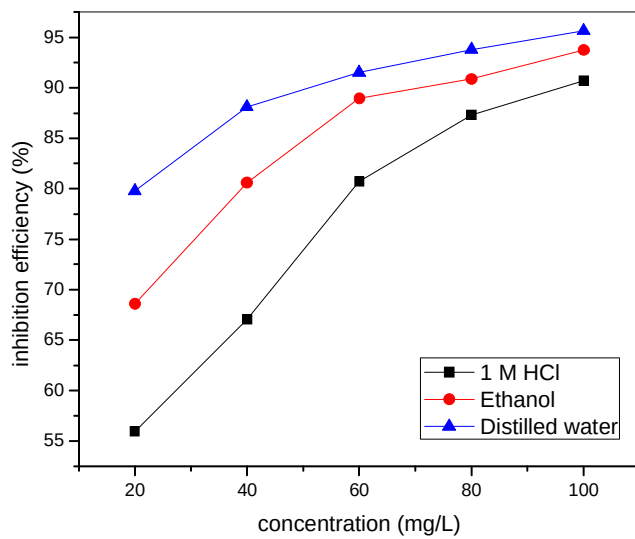
**Table 2. Effect of various inhibitor extracts on % I.E and  $\theta$  for Al corrosion in 1M HCl at 333k**

| Concentration<br>mg/l | 1M HCl extract of<br><i>Ocimum gratissimum</i> | Ethanol extract of<br><i>Ocimum gratissimum</i> | Distilled water extract of<br><i>Ocimum gratissimum</i> |          |        |          |
|-----------------------|------------------------------------------------|-------------------------------------------------|---------------------------------------------------------|----------|--------|----------|
|                       | % I.E.                                         | $\theta$                                        | % I.E.                                                  | $\theta$ | % I.E. | $\theta$ |
| 20.00                 | 4.83                                           | 0.05                                            | 7.81                                                    | 0.08     | 15.11  | 0.15     |
| 40.00                 | 9.15                                           | 0.09                                            | 15.50                                                   | 0.16     | 18.37  | 0.18     |
| 60.00                 | 14.16                                          | 0.14                                            | 21.55                                                   | 0.22     | 24.60  | 0.25     |
| 80.00                 | 16.67                                          | 0.17                                            | 23.94                                                   | 0.24     | 30.64  | 0.31     |
| 100.00                | 19.10                                          | 0.19                                            | 28.05                                                   | 0.28     | 35.69  | 0.36     |

The result shows that distilled water extract exhibited highest inhibition efficiency and surface coverage when compared to values obtained for ethanolic and 1M HCl extracts, respectively. The highest inhibition efficiency and surface coverage of distilled water extract may probably be attributed to the presence of more complex chemical composition of distilled water extract. It has been reported (Alinnor and Aneke, 2009) that ethanolic extract of *Ocimum gratissimum* leaf contains alkaloid, saponins, flavonoids and tannins. The adsorption of these species from extracts on aluminium surface reduces surface area available for corrosion, thereby increasing inhibition efficiency and surface coverage.

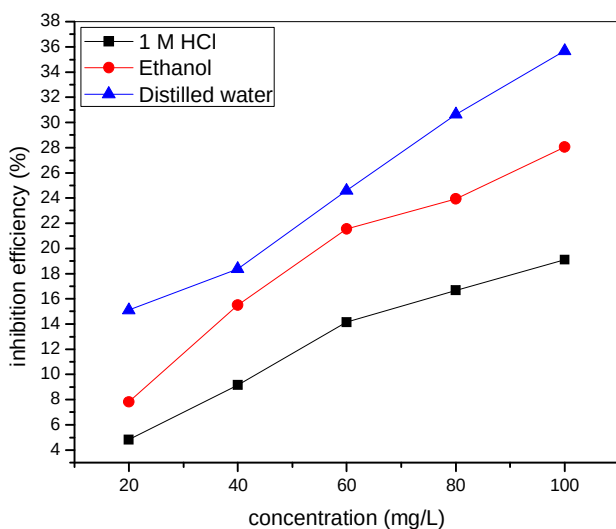
Table 2 revealed that % I.E and  $\theta$  decreases at 333 K when compared to values obtained at 303 K. The decrease in % I.E and  $\theta$  at 333 K may be explained as a result of increase in average kinetic energy of components of extracts, thus making adsorption between components of extracts and Al surface insufficient to retain the species at binding site. This could lead to desorption or cause species to bounce off surface of aluminium instead of colliding and combining with it. Therefore, increase in temperature may be associated with decrease in stability of components – aluminium surface complex. Report (Odiongenyi et al; 2009) have shown that increase in temperature decreases inhibition efficiency of corrosion of mild steel in  $H_2SO_4$  using ethanolic extract of *Vernonia amygdalina*. Ebenso et al (2008) working on corrosion of mild steel in  $H_2SO_4$  using ethanolic extract of *Piper guinensis* as green corrosion inhibitor reported decrease in inhibition efficiency at higher temperature. Noor (2007) working on corrosion inhibition of mild steel in acidic solutions with aqueous extract of Fenugreek leaves reported decrease in inhibition efficiency at higher temperature.

Figs. 3 and 4 shows plot of inhibition efficiency versus different concentrations of inhibitor at 303 K and 333 K, respectively. The result indicates that inhibition efficiency was high at low temperature of 303 K when compared to values obtained at 333 K. This observation has been explained earlier in this report. The trend of inhibition efficiency were in order: Distilled  $H_2O > C_2H_5OH > 1M$  HCl.



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Fig 3. Variation of inhibition efficiency with concentrations of 1 M HCl ,ethanol and distilled water extract of *Ocimum gratissimum* at 303 K.

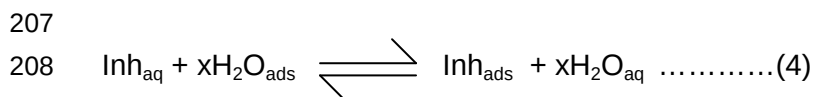


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Fig 4. Variation of inhibition efficiency with concentration of 1 M HCl, ethanol and distilled water extract of *Ocimum gratissimum* at 333 K.

### 203 3.3 Adsorption consideration

204 The adsorption of inhibitor on surface of corroding aluminium sample may be  
205 regarded as a substitution process between inhibitor compound in aqueous phase  
206 and water molecules adsorbed on aluminium surface:



209 where x is size ratio, the number of water molecules displaced by one molecule of  
210 organic inhibitor. When the equilibrium as described in Eq (4) is reached, it is  
211 possible to obtain different forms of adsorption isotherm.

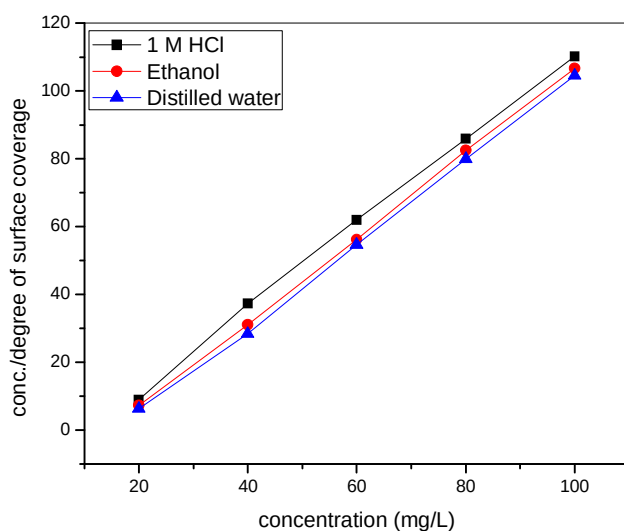
212 In the present study Langmuir adsorption isotherm was found to be suitable for the  
213 experimental findings and had been used to describe the adsorption characteristic  
214 of inhibitor. Langmuir adsorption isotherm is expressed in Eq (5) (Schockry et  
215 al;1998).

$$216 \frac{C_{\text{inh}}}{\theta} = \frac{1}{k} + C_{\text{inh}} \dots\dots\dots(5)$$

217 where  $C_{\text{inh}}$  is inhibitor concentration, K is equilibrium constant of adsorption,  $\theta$  is  
218 degree of surface coverage.

219 Figs. 5 and 6 shows plot of  $C_{\text{inh}}/\theta$  versus  $C_{\text{inh}}$  at 303 K and 333 K, respectively  
220 for 1M HCl, ethanol and distilled water extracts of inhibitor. Figs. 5 and 6 were  
221 linear indicating that adsorption of inhibitor is consistent with assumptions of  
222 Langmuir adsorption isotherm meaning there is no interaction between adsorbed  
223 species.

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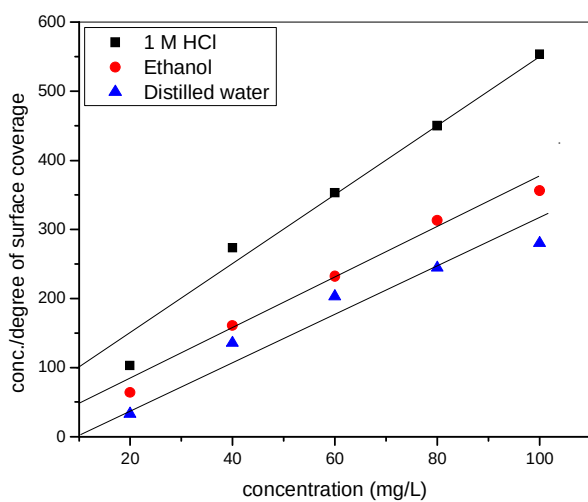
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232 Fig 5. Langmuir adsorption isotherm at 303 K for 1 M HCl , ethanol and distilled  
 233 water *Ocimum gratissimum* extracts.

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238 Fig 6. Langmuir adsorption isotherm at 333 K for 1 M HCl ,ethanol and distilled  
 239 water *Ocimum gratissimum* extracts.

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241 Adsorption of inhibitor extracts on Al surface was found to follow Flory – Huggins  
 242 isotherm expressed in Eq (6) (Oguzie et al;2004):

$$\log (\theta / C_{inh}) = \log K_c + x \log (1 - \theta) \quad \text{.....(6)}$$

where  $\theta$  is degree of surface coverage,  $C_{inh}$  is inhibitor concentration,  $x$  is number of water molecules replaced by one inhibitor molecule and  $K_c$  is equilibrium constant for adsorption process. Figs 7, 8 and 9 shows Flory – Huggins adsorption isotherm for different extracts of inhibitor using 1 M HCl, ethanol and distilled water at 303 K and 333 K, respectively. The calculated values for  $x$  and  $K_c$  for 1 M HCl extract of inhibitor were 1.00 and 0.007 for 303 K and 0.40 and 0.74 for 333 K, respectively. The values for  $x$  and  $K_c$  obtained with ethanol extract of inhibitor were 1.0 and 0.006 for 303 K, and 0.30 and 0.63 for 333 K, respectively. Also calculated values for  $x$  and  $K_c$  with distilled water extract of inhibitor were 1.51 and 0.005 for 303 K, and 0.10 and 0.58 for 333 K, respectively. The result indicates that values of  $x$  are unity for both 1 M HCl and ethanol extracts, while distilled water extract of inhibitor is more than unity, indicating that each molecule of inhibitor is attached to one active site on Al surface.

The values of free energy of adsorption,  $\Delta G_{ads}$  of 1 M HCl, ethanol and distilled water extracts of inhibitor on Al surface were calculated using Eq (7) (Noor,2007):

$$\Delta G_{ads} = - 2.303 RT \log (55.5K) \quad \text{.....(7)}$$

Where  $R$  is gas constant,  $T$  is temperature and  $K$  is equilibrium constant of adsorption, given as  $K = \theta / (1 - \theta)$  and 55.5 is concentration of water in solution. The values of  $\Delta G_{ads}$  were negative in 303K and 333K indicating spontaneous adsorption of inhibitor on surface of aluminium, and the propose mechanism is physical adsorption ( $\Delta G_{ads} < 40$  kJ/mol) (Ebenso,2004; Bilgic and Sahin,2001).

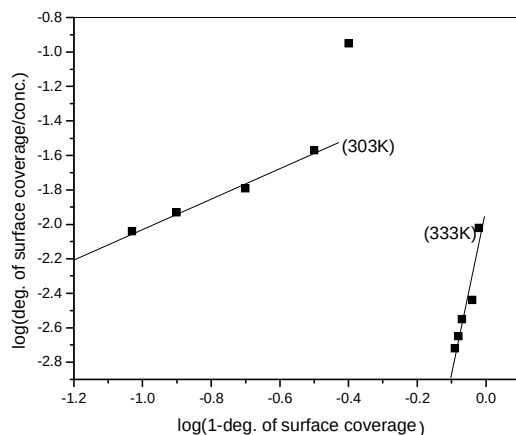
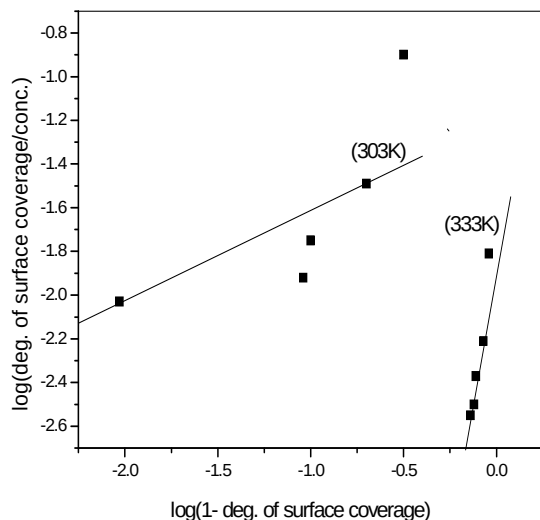


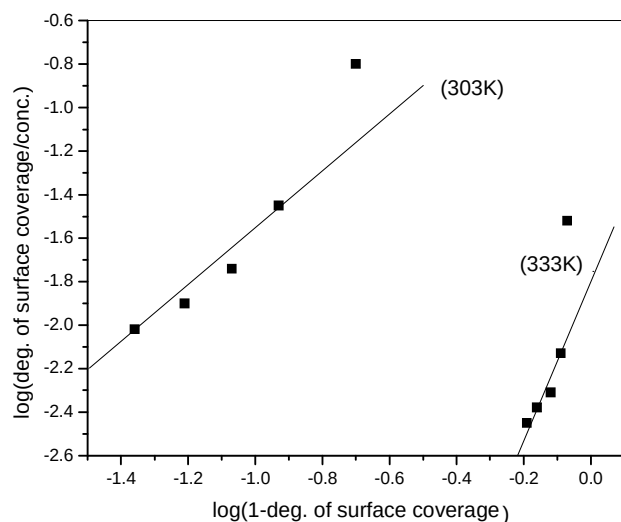
Fig 7. Flory-Huggins adsorption isotherm at 303 K and 333 K for 1M HCl *Ocimum gratissimum* extract.



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272 Fig 8. Flory-Huggins adsorption isotherm at 303 K and 333 K for ethanol *Ocimum*  
 273 *gratissimum* extract.

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276 Fig 9. Flory-Huggins adsorption isotherm at 303 K and 333 K for distilled water  
 277 *Ocimum gratissimum* extract.

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### 279 3.4 Effect of Temperature

280 The influence of temperature on weight loss of Al sample in 1 M HCl in presence  
 281 and absence of different concentrations of inhibitor has been depicted in figs 1 and

282 2. The increase in temperature decreases inhibition efficiency and degree of surface  
 283 coverage. The reasons for this observation has been explained earlier in this study.  
 284 In order to calculate apparent activation energy,  $E_a$ , for corrosion reaction of Al in  
 285 absence and presence of various concentrations of inhibitor, the Arrhenius equation  
 286 was used:

287  $\log (i_2/i_1) = E_a / 2.303R [1/T_1 - 1/T_2]$  .....(8)

288 where  $i_1$  and  $i_2$  are corrosion rates at temperatures  $T_1$  and  $T_2$ , respectively, and  $R$   
 289 is gas constant.

290 The heat of adsorption ( $Q_{ads}$ ) of inhibitor on surface of Al was evaluated using  
 291 equation (9) (Bhajiwala and Vashi, 2001);

292  $Q_{ads} = 2.303R [\log (\theta_2/1-\theta_2) - \log (\theta_1/1-\theta_1)] \times T_1 T_2 / T_2 - T_1$  .....(9)

293 where  $\theta_1$  and  $\theta_2$  are degree of surface coverage at temperatures  $T_1$  and  $T_2$ . The  
 294 calculated values of apparent activation energy  $E_a$ , and heat of adsorption,  $Q_{ads}$  of  
 295 different inhibitor extracts are shown in Tables 3, 4 and 5, respectively.

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298 **Table 3: Values of thermodynamic parameters for adsorption of distilled**  
 299 **water extract of *Ocimum gratissimum* on surface of aluminium in 1 M HCl.**

| Concentration<br>of <i>Ocimum</i><br><i>gratissimum</i><br>(mg /l) | Activation<br>energy, $E_a$<br>(KJ/mol) | Heat of<br>adsorption<br>$Q_{ads}$ KJ/mol) | Free energy<br>change $\Delta G_{ads}$<br>(KJ/mol) of<br>adsorption at<br>303k | Free energy<br>change, $\Delta G_{ads}$<br>(KJ/mol) of<br>adsorption at<br>333k |
|--------------------------------------------------------------------|-----------------------------------------|--------------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Blank                                                              | 5.24                                    | -                                          | -                                                                              | -                                                                               |
| 20.00                                                              | 45.02                                   | -86.68                                     | -13.58                                                                         | -5.77                                                                           |
| 40.00                                                              | 58.64                                   | -97.72                                     | -15.17                                                                         | -6.36                                                                           |
| 60.00                                                              | 65.82                                   | -97.89                                     | -16.12                                                                         | -7.30                                                                           |
| 80.00                                                              | 72.18                                   | -98.82                                     | -16.96                                                                         | -8.06                                                                           |
| 100.00                                                             | 79.90                                   | -102.90                                    | -17.91                                                                         | -8.64                                                                           |

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309 **Table 4. Values of thermodynamic parameters for adsorption of ethanol**  
 310 **extract of *Ocimum gratissimum* on surface of aluminium in 1 M HCl.**

| Concentration of<br><i>Ocimum</i><br><i>gratissimum</i><br>(mg /l) | Activation<br>energy, $E_a$<br>(KJ/mol) | Heat of<br>adsorption<br>$Q_{ads}$ (KJ/mol) | Free energy<br>Change $\Delta G_{ads}$<br>(KJ/mol) of<br>adsorption at<br>303k | Free energy<br>change, $\Delta G_{ads}$<br>(KJ/mol) of<br>adsorption at<br>333k |
|--------------------------------------------------------------------|-----------------------------------------|---------------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Blank                                                              | 5.24                                    | -                                           | -                                                                              | -                                                                               |
| 20.00                                                              | 35.12                                   | -71.22                                      | -12.09                                                                         | -3.90                                                                           |
| 40.00                                                              | 46.02                                   | -87.25                                      | -13.71                                                                         | -5.85                                                                           |
| 60.00                                                              | 59.58                                   | -94.50                                      | -15.38                                                                         | -6.86                                                                           |
| 80.00                                                              | 63.99                                   | -96.60                                      | -15.91                                                                         | -7.21                                                                           |
| 100.00                                                             | 72.93                                   | -102.04                                     | -16.94                                                                         | -7.75                                                                           |

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313 **Table 5. values of thermodynamic parameters for adsorption of 1 M HCl**  
 314 **extract of *Ocimum gratissimum* on surface of aluminium in 1 M HCl.**

| Concentration of<br><i>Ocimum</i><br><i>gratissimum</i><br>(mg /l) | Activation<br>energy, $E_a$<br>(KJ/mol) | Heat of<br>adsorption<br>$Q_{ads}$ (KJ/mol) | Free energy<br>Change $\Delta G_{ads}$<br>(KJ/mol) of<br>adsorption at<br>303k | Free energy<br>change, $\Delta G_{ads}$<br>(KJ/mol) OF<br>adsorption at<br>333k |
|--------------------------------------------------------------------|-----------------------------------------|---------------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Black                                                              | 5.24                                    | -                                           | -                                                                              | -                                                                               |
| 20.00                                                              | 26.60                                   | -84.04                                      | -10.72                                                                         | -2.61                                                                           |
| 40.00                                                              | 33.34                                   | -84.06                                      | -11.89                                                                         | -4.34                                                                           |
| 60.00                                                              | 46.60                                   | -90.07                                      | -13.72                                                                         | -5.58                                                                           |
| 80.00                                                              | 57.40                                   | -90.41                                      | -14.98                                                                         | -6.07                                                                           |
| 100.00                                                             | 65.25                                   | -98.95                                      | -15.86                                                                         | -6.48                                                                           |

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316 The results shown in tables 3, 4 and 5 of different inhibitor extract indicates that  
 317 apparent activation energy  $E_a$ , increases as inhibitor concentration increases.  
 318 Activation energy of distilled water extract ranged between 45.02 to 79.90 KJ/mol.  
 319 While the activation energies of ethanol and 1 M HCl extracts of inhibitor ranged  
 320 between 35.12 to 72.93 KJ/mol and 26.60 to 65.25 KJ/mol, respectively. Since  
 321 corrosion primarily occurs at surface sites free of adsorbed inhibitor, the higher  $E_a$   
 322 values in inhibited solutions imply that extracts mechanically screen the active sites  
 323 of Al surface thereby decreasing the surface area available for corrosion. The order  
 324 of apparent activation energy,  $E_a$  of different extracts were in order: distilled  $H_2O$  >  
 325  $C_2H_5OH$  > 1 M HCl.

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327 The heat of adsorption,  $Q_{ads}$  were all negative and ranged from – 86.68 to –102.90  
328 KJ/mol for distilled water extract, while ethanol and 1 M HCl extracts ranged from –  
329 71.22 to –102.04 KJ/mol and – 84.04 to – 98.95 KJ/mol, respectively. The negative  
330  $Q_{ads}$  values indicates that adsorption and hence inhibition efficiency decreases as  
331 temperature increases, supporting the earlier proposed physisorption mechanism  
332 (Bhajiwala and Vashi, 2001).

333

#### 334 4. CONCLUSION

335 This study indicates that extract of *Ocimum gratissimum* inhibits Al surface in  
336 presence of 1 M HCl. The corrosion process is inhibited by adsorption of extracts on  
337 aluminium surface. Inhibition efficiency increase with increase in inhibitor  
338 concentrations. The result of the analysis shows that inhibition efficiency and degree  
339 of surface coverage decreases as temperature increases. Activation energies of  
340 different extracts increases as concentration of inhibitor increases. The negative  
341 values of  $\Delta G_{ads}$  shows that adsorption of inhibitor on surface of aluminium is  
342 spontaneous. The adsorption behaviour were approximated by Langmuir and Flory  
343 – Huggins isotherms. The trend of inhibition efficiency of different extracts were in  
344 order: Distilled  $H_2O$  >  $C_2H_5OH$  > 1M HCl  
345

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349

#### 350 COMPETING INTERESTS

351 Authors have declared that no competing interest exist

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#### 354 AUTHORS' CONTRIBUTIONS

355

356 This work was carried out in collaboration between the authors. AIJ designed the study,  
357 performed the graphics and tables, wrote the first protocol, wrote the first manuscript. EPM  
358 managed the analysis of the study and literature research. All authors read and approved  
359 the final manuscript.

360

#### 361 REFERENCES

362 Abdel—Gaber A.M; Khamis E; Abo—Eldahab H; Adeel Sh. (2008). Inhibition  
363 of aluminium corrosion in alkaline solutions using natural

364 compound. Mater.Chem. Phys. 109, 297- 305.

365

366 Abiola,O.K; Oforka, N.C; Ebenso, E.E; Nwinuka,N.M. (2007). Eco- friendly

367 corrosion inhibitor: Inhibitive action of Delonix regia extract for the corrosion

368 of aluminium in acidic medium. Anti – Corrosion methods and material, 54,

369 219 – 224.

370 Alinnor,I.J; Aneke J.N. (2009). Study of Phytochemical and antibacterial Evaluation

371 of crude extracts of Ocimum gratissimum. Int. J. Chem. Sci; 2 (2), 286 -292.

372

373 Aytac A, .Ozmen U; kabasakaloglu M. (2005). Investigation of some Schiff bases

374 as acidic corrosion of alloy AA3102. Mater. Chem. Phys. 89 (1) , 176-181.

375

376 Bhajiwala H.M; Vashi R.T. (2001). Ethanolamine, diethanolamine and

377 triethanolamine as corrosion inhibitors for zinc in binary acid mixture ( $\text{HNO}_3$

378  $+\text{H}_3\text{PO}_4$ ). Bull. Electrochem. 17, 411 – 448.

379

380 Bilgic S; Sahin M. (2001). The corrosion inhibition of austenitic chromium – nickel

381 steel in  $\text{H}_2\text{SO}_4$  by 2 – butyn -1-ol. Mater. Chem. Phys. 70, 290 – 295.

382

383 Cotton F.B; Wilkinson G. (1972). Advanced Inorganic Chemistry. A

384 comprehensives text. 3<sup>rd</sup> ed. John Wiley and Sons. Inc. New York.

385

386 Ebenso E.E; P.C. Okafor P.C; Offiong O.E; Ita B.I; Ibok U.J; Ekpe U.J. (2001).

387 Comparative investigation into the kinetics and corrosion inhibition of

388 aluminium alloy AA1060 in acidic medium, Bull. of Electrochemistry, 17 (10),

389 459 – 464.

390

391 Ebenso E.E. (2004). Effect of methyl red and halide ions on the corrosion inhibition

392 of aluminium in  $\text{H}_2\text{SO}_4$  Part 2. Bull. Electrochem. 20, 551- 559.

393

394 Ebenso E.E; Eddy N.O; Odiongenyi A.O. (2008). Corrosion inhibitive properties

395 and adsorption behaviour of ethanol extract of Piper guinensis as a green

396 corrosion inhibitor for mild steel in  $\text{H}_2\text{SO}_4$ . African J. Pure and Appl.

397 Chemistry, 2 (11), 107 -115

398

399

400 Eddy N.O; Ebenso E.E. (2008). Adsorption and inhibitive properties of ethanol  
 401 extract of *Musa sapientum* peels as a green corrosion in acidic medium.  
 402 African J. Pure Appl. Chem. 2 (6), 46-54.  
 403  
 404 Elewady G.Y; El- Said I.A; Fouda A.S. (2008). Effect of anions on the corrosion  
 405 inhibition of aluminium in HCl using ethyl trimethyl ammonium bromide as  
 406 cationic inhibitor. Int. J. Electrochem. Sci. 3, 644- 655.  
 407  
 408 Kliskic, M; J. Radoservic J; Gudic S; Katalinic V. (2000). Aqueous extract of  
 409 *Rosemaris officinalis* L. as inhibitor of Al-mg alloy corrosion in chloride  
 410 solution. J. Appl. Electrochem. 30, 823– 830.  
 411  
 412 Madkour, L.M; R.M. Issa R.M; El – Ghrabawy I.M. (1999). Kinetics of substituted  
 413 bis -and mono-azo dyes as corrosion inhibitors for aluminium in hydrochloric  
 414 acid and sodium hydroxide. J. Chemical Research, 8, 408 -409.  
 415  
 416 Moussa M.N; Fouda A.S; A. T.Taha A.T; Elnenaa A. (1998). Some  
 417 thiosemicarbazide derivatives as corrosion inhibitors for aluminium in sodium  
 418 hydroxide solution. Bulletin of the Korean Chemical Society, 9, 192 – 195.  
 419  
 420 Noor, E.A. (2007). Temperature effects on the corrosion inhibition of mild steel in  
 421 acidic solutions by aqueous extract of Fenugreek leaves. Int. J.  
 422 Electrochem. Sci. 2, 996 – 1017.  
 423 Odiongenyi A.O; Odoemelum S.A; Eddy N.O. (2009). Corrosion inhibition and  
 424 adsorption properties of ethanol extract of *vernonia amygdalina* for the  
 425 corrosion of mild steel in H<sub>2</sub>SO<sub>4</sub>. Portugaliae Electrochimica Acta. 2 (1), 34-  
 426 45.  
 427  
 428 Oguzie E.E; Okolue B.N; Ebenso E.E; Onuoha G.N; Onuchukwu A.I. (2004).  
 429 Evaluation of the inhibitory effect of methylene blue dye on the corrosion of  
 430 aluminium in hydrochloric acid. Mater. Chem. Phys. 87, 394 – 401.  
 431 Oguzie E.E. (2005). Inhibition of acid corrosion of mild steel by *Telfaria occidentalis*  
 432 extract. Pigment and Resin Technol. 34, 321 – 326.  
 433  
 434

435 Schockry H; Yuasa M; Sekine I; Issa R.M; El-baradie H.Y. Gomma G.K. (1998).  
436 Corrosion inhibition of mild steel by Schiff base compounds in various  
437 aqueous solution. Part I. Corros. Sci. 40, 2173 - 2186  
438  
439 Umoren S.A; Ebenso E.E. (2008). Studies of anit-corrosion effect of Raphia  
440 hookeri exudates gum-halide mixtures for aluminium corrosion in acidic  
441 medium. Pigment and Resin Technol. 37, 173 – 182.  
442  
443 USDA.(2008). (United States Department of Agriculture) Agricultural Research  
444 Service.