

# Effect of Xanthan gum on the Corrosion Protection of Aluminium in HCl medium

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## ABSTRACT

The inhibition of the corrosion of aluminium in 1.0 M HCl solution by xanthan gum has been studied using weight loss and polarization measurements techniques. Inhibition was found to increase with increasing concentration of the xanthan gum. The effect of temperature and immersion time was also studied. The inhibition was found to occur via adsorption on the metal surface following Temkin and El-Awady adsorption isotherms. The apparent activation energy as well as free energy of adsorption,  $\Delta G_{ads}$  for the inhibition process was calculated. Polarization measurements indicate the inhibitor is of mixed-type, with predominant inhibitive effect on cathodic partial reaction.

**Keywords:** Acid inhibition; Aluminium; Polarization; Weight loss.

## 1. INTRODUCTION

The use of acid solutions in some industrial operations is so much important that the study of the effect of these solutions on industrial metallic equipments has become essential. Among acidic solutions, hydrochloric acid, also known as muriatic acid used in the pickling of metals, oil well acidizing and ore processing is more economical, efficient and straight forward compared to other mineral acids [1, 2].

However, the study of the corrosion behaviour of aluminium in acidic media has continued to receive considerable attention because of its many applications. Aluminium, however, relies on the formation of a compact, coherent passive oxide film for its corrosion resistance in chemically challenged operations [3]. This oxide film is amphoteric, hence dissolves readily when the metal is exposed to strong aggressive environments [4]. Consequently, bare metal surface sites become exposed to the aggressive solution after the breakdown of the oxide film, resulting to a sequence of electrochemical reactions as the metal dissolves.

In effort to mitigate aluminium corrosion, corrosion scientists are relentlessly seeking better and more efficient ways of combating the corrosion of metals [5-10]. The use of inhibitors is one of the most practical and efficient method for protection against corrosion and prevention of unexpected metal dissolution and acid consumption, especially in acid solutions [11-15]. A particular advantage of corrosion inhibitor is that it can be implemented or changed in-situ without disrupting a process. Different organic and inorganic compounds have been studied as

inhibitors to protect metals from corrosive attack. The efficiency of these organic corrosion inhibitors is related to the presence of polar functions with S, O or N atoms in the molecule, heterocyclic compounds and  $\pi$ -electrons [16-20]. Inhibition can only be effected if the relevant ingredients in the inhibitor can adsorb onto the metal surface and block the active surface sites [21] or displace the water molecules adsorbed on the active sites [22] while creating a protective coating on the metal surface which will continuously interfere with the electrical circuit required to initiate the corrosion process. Then, the adsorbed inhibitor could slow down corrosion processes by either:

- increasing the anodic or cathodic polarization behaviour,
- reducing the movement or diffusion of ions to the metallic surface, or
- increasing the electrical resistance of the metallic surface.

Although, many synthetic compounds show good anti-corrosive activity, most of them are highly toxic to both human beings and the environment [23], and they are often expensive and non-degradable. Thus, the use of benign products as corrosion inhibitors has become a key area of research, primarily on account of their eco-friendliness.

Polymeric materials have been reported to be effective corrosion inhibitors [24-28]. It has been accounted that the inhibitive power of polymers is related structurally to the aromatic rings and hetero-atoms which are the major active centres of adsorption, as well as their inherent film-forming characteristics.

Xanthan gum, therefore, is a polymer from bacterium, *Xanthomonas campestris*. The use of xanthan gum is very beneficial to the food industry for adding viscosity and suspension, and to stabilize mixtures of liquids within food products. The structure of xanthan gum (Fig. 1) consists of a primary structure consisting of repeated pentasaccharide units formed by two glucose units, two mannose units and a glucuronic acid unit. Its main chain consists of beta-D-glucose units with linkages at the 1

and 4 positions, very similar structure to cellulose. The repeating segments of pentasaccharide units give xanthan gum its backbone, which is a unique characteristic of this heteropolysaccharide.

This paper aims to investigate the inhibitive capability of xanthan gum on aluminium corrosion in hydrochloric acid solution using weight loss and polarization measurement techniques.

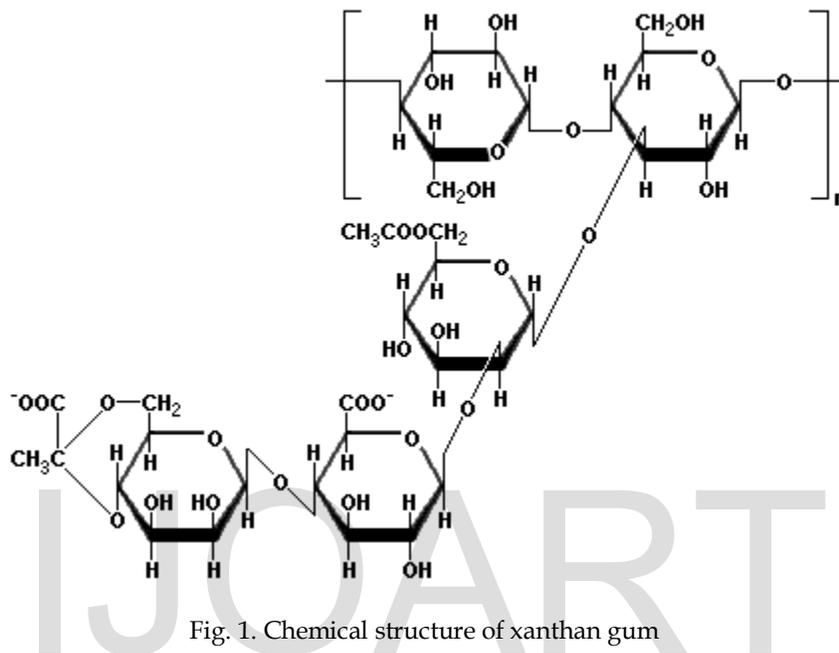


Fig. 1. Chemical structure of xanthan gum

## 2. EXPERIMENTAL

The weight loss measurements according to standard method reported by some authors [23,28,29] were carried out in a 250 ml capacity glass beaker. The blank acid test solution was prepared using serial dilution principle. Blank hydrochloric acid solution was prepared in the concentration of 1.0 M HCl solution. The solutions containing xanthan gum additive were prepared in five different concentrations from 1.0 - 5.0 g/l. The xanthan gum used was obtained from Sigma Aldrich chemical company. The hydrochloric acid was of BDH analytical reagent chemical.

The study was carried out first at ambient temperature,  $28 \pm 1$  °C and later in a thermostatic water bath equilibrated at 40, 50 and 60 °C. The aluminium samples used were press-cut mechanically into coupons of dimension (length = 4 cm, width = 3 cm and thickness = 0.045 cm) and used without further polishing but were degreased in acetone. The aluminium used has the following chemical composition (wt %): Si, 0.842; Fe, 0.898; Cu, 0.028; Mn, 0.081; Mg, 0.026; Zn, 0.010; Ti, 0.015; Cr, 0.006; Ni, 0.003; V, 0.009 and balance Al. The coupons were initially weighed and suspended in 200 ml of the test solution and kept under aerated condition and were

monitored at 24-h and 48-h respectively. For the temperature study, experiments were conducted for 3 hs. At the end of the tests, the coupons were retrieved, washed with double distilled water, and then with acetone, dried and then reweighed using an analytical balance (precision =  $\pm 0.01$  g).

Three measurements were performed in each case and the mean value of the weight loss has been reported. The corrosion rate (CR) of the aluminium in the test solutions were calculated from the expression

$$CR(mm/y) = \left( \frac{87,600 \Delta W}{\rho A t} \right) \quad (1)$$

where  $\Delta W$  is the weight loss (g),  $\rho$  the density of the aluminium ( $g/cm^3$ ),  $A$  the surface area and  $t$  the exposure time.

From the values of weight loss in the absence ( $W_L^{blk}$ ) and presence of xanthan gum ( $W_L^{xs}$ ), the inhibition efficiency ( $I$  %) over the exposure time period were calculated according to the following equation

$$I\% = \left( 1 - \frac{W_L^{xg}}{W_L^{blk}} \right) \times 100 \quad (2)$$

Polarization experiments were performed using a VERSASTAT 3 Advanced Electrochemical System operated with V3 Studio electrochemical software as described elsewhere [30]. A conventional three-electrode glass cell was used for the experiments. Test coupons with 1 cm<sup>2</sup> exposed surface area were used as working electrode and a graphite rod as counter electrode. The reference electrode was a saturated calomel electrode (SCE), which was connected *via* a Luggin's capillary. The working electrode was immersed in a test solution for 30 minutes to attain a stable open circuit potential prior to electrochemical measurements. All experiments were undertaken in 200 ml of stagnant aerated solutions at 28±1 °C. Potentiodynamic polarization studies

were carried out in the potential range -250 to 1600 mV at a scan rate of 0.333 mV s<sup>-1</sup>. Each test was run in triplicate to verify the reproducibility of the systems.

### 3. RESULTS AND DISCUSSION

#### 3.1 Weight loss measurements

##### 3.1.1 Weight loss, corrosion rate and inhibition efficiency

The effect of addition of xanthan gum at different concentrations on the corrosion of aluminium in 1.0 M HCl was investigated using weight loss technique at three temperature regimes of 40, 50 and 60 °C after 3 h of immersion period. The calculated values of corrosion rate, inhibition efficiency and degree of surface coverage are given in Table 1.

**Table 1**

Calculated values of corrosion rate, inhibition efficiency and degree of surface coverage for aluminium dissolution in 1.0 M HCl solution in the absence and presence of xanthan gum as a function of temperature variation.

| System  | Corrosion rate (mm/y) |        |        | Inhibition efficiency (I %) |       |       | Degree of surface coverage (θ) |       |       |
|---------|-----------------------|--------|--------|-----------------------------|-------|-------|--------------------------------|-------|-------|
|         | 40 °C                 | 50 °C  | 60 °C  | 40 °C                       | 50 °C | 60 °C | 40 °C                          | 50 °C | 60 °C |
| Blank   | 181.73                | 203.24 | 235.26 | -                           | -     | -     | -                              | -     | -     |
| 1.0 g/l | 156.84                | 169.99 | 177.83 | 19.05                       | 18.75 | 17.65 | 0.19                           | 0.19  | 0.18  |
| 2.0 g/l | 134.21                | 148.19 | 158.93 | 28.57                       | 27.08 | 27.45 | 0.29                           | 0.27  | 0.27  |
| 3.0 g/l | 102.35                | 128.17 | 133.21 | 42.86                       | 41.67 | 41.18 | 0.43                           | 0.42  | 0.41  |
| 4.0 g/l | 72.12                 | 88.92  | 109.86 | 61.90                       | 56.25 | 52.94 | 0.62                           | 0.56  | 0.53  |
| 5.0 g/l | 57.08                 | 65.86  | 80.53  | 69.05                       | 68.75 | 64.71 | 0.69                           | 0.69  | 0.65  |

Fig. 2 shows the plot of weight loss versus concentration of inhibitor for aluminium dissolution in 1.0 M HCl solution in the absence and presence of different concentrations of xanthan gum at 40, 50 and 60 °C. The figure shows a reduction of weight loss of the metal coupons in the presence of the additive compared to the free acid solution (blank). Further investigation of the figure revealed that the loss in weight of the coupons at 40 °C decreases as the concentration of the additive increases.

Similar trend was observed for other temperatures of 50 and 60 °C but with higher values of weight loss. In the same manner, the corrosion rate of aluminium decreases with increase in concentration of the additive. This indicates that xanthan gum in the solution inhibits the corrosion of aluminium in 1.0 M HCl solution and that the extent of corrosion depends on the amount of the xanthan gum present.

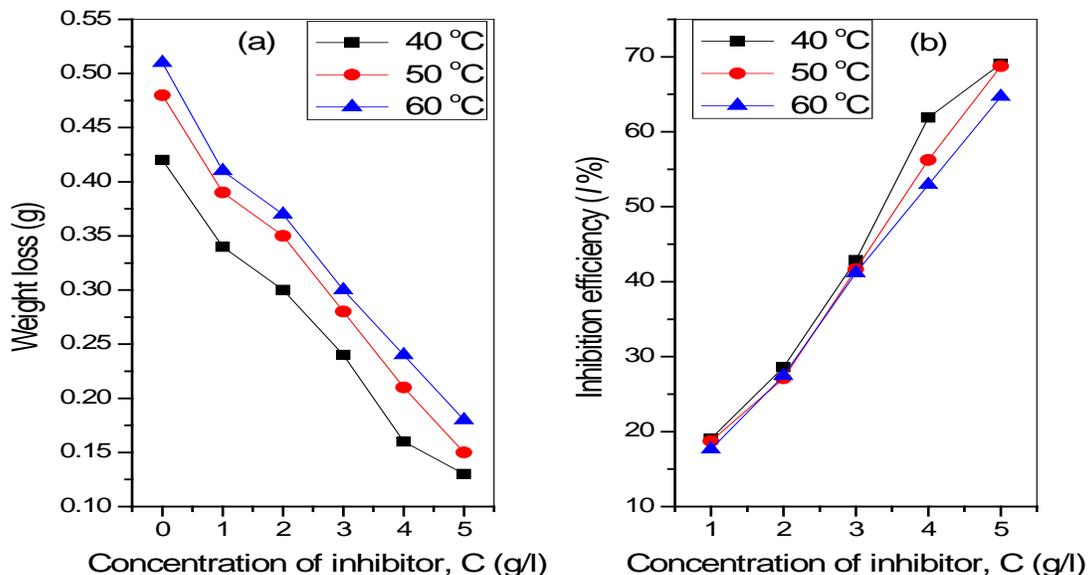


Fig. 2. Plots of (a) weight loss and (b) inhibition efficiency against concentration of xanthan gum for aluminium dissolution in 1.0 M HCl solution at 40, 50 and 60 °C.

Similarly, calculated values of corrosion rate, inhibition efficiency and degree of surface coverage for aluminium exposed to 1.0 M HCl solution at ambient

temperature, 28±1 °C as a function of concentration of xanthan gum is presented in Table 2.

**Table 2**

Calculated values of corrosion rate, inhibition efficiency and degree of surface coverage for aluminium dissolution in 1.0 M HCl solution in the absence and presence of xanthan gum at ambient temperature, 28±1 °C as a function of immersion time.

| Immersion time (h) | System  | Corrosion rate (mm/y) | Inhibition efficiency (I %) | Degree of surface coverage (θ) |
|--------------------|---------|-----------------------|-----------------------------|--------------------------------|
| 24                 | Blank   | 53.84                 | -                           | -                              |
|                    | 1.0 g/l | 51.76                 | 5.94                        | 0.06                           |
|                    | 2.0 g/l | 51.21                 | 6.93                        | 0.07                           |
|                    | 3.0 g/l | 50.84                 | 7.92                        | 0.08                           |
|                    | 4.0 g/l | 36.51                 | 32.67                       | 0.33                           |
|                    | 5.0 g/l | 33.05                 | 38.61                       | 0.39                           |
| 48                 | Blank   | 32.78                 | -                           | -                              |
|                    | 1.0 g/l | 26.70                 | 20.33                       | 0.20                           |
|                    | 2.0 g/l | 26.15                 | 21.95                       | 0.22                           |
|                    | 3.0 g/l | 25.50                 | 22.76                       | 0.23                           |
|                    | 4.0 g/l | 19.60                 | 40.65                       | 0.41                           |
|                    | 5.0 g/l | 18.39                 | 43.90                       | 0.44                           |

These assays are important to show the stability of xanthan gum over time. Plots of weight loss versus concentration of inhibitor shown in Fig. (3a) reveal that weight of metal loss increased with time but decreased with increasing concentration of inhibitor. Again, it could be noted (Table 2) that the rate of aluminium corrosion is reduced upon addition of xanthan gum for both the

immersion times. This behaviour reflects the inhibitory effect of xanthan gum on the aluminium corrosion in HCl solution. It is worth noting that there is no degradation of the xanthan gum with time, rather, the adsorption of xanthan gum onto the aluminium surface is found to be slow, suggesting that the adsorption process is time-dependent. This behaviour is characteristic of polymers

where, by virtue of their macromolecular nature, will be soluble, depending on the nature of the solvent (HCl

solution) and solute (xanthan gum), viscosity of the medium, polymer texture and molecular weight.

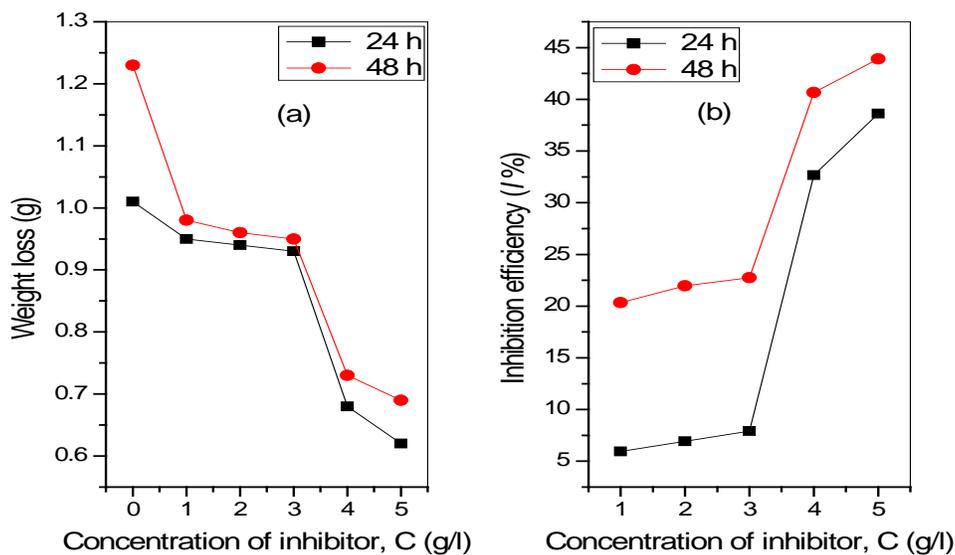


Fig. 3. Plots of (a) weight loss and (b) inhibition efficiency against concentration of xanthan gum for aluminium dissolution in 1.0 M HCl solution as a function of immersion time at  $28 \pm 1$  °C.

To further explain the adsorbability of xanthan gum from HCl solution, it is important to note that dissolution of a polymer is necessarily slow and is a two-staged process [31]. First, the solvent molecules diffuse into the polymer, producing a swollen gel; second, the gel breaks down slowly forming a true solution. When this occurs, the adsorption of the polymer molecules onto the metal surface will be rapid and efficient. In some cases and depending on the nature of the polymer, only the first step occurs, in which case the adsorption of xanthan gum on the metal surface will be limited. However, if the polymer-polymer interaction forces can be overcome by polymer-solvent attraction, then the second stage will follow, but slowly. In some other cases, materials with strong polymer-polymer intermolecular forces due to say, crosslinking, crystallinity, or strong hydrogen bonding will not dissolve in any solvent at ordinary temperatures and will exhibit only a limited degree of swelling.

On account of the above factors, xanthan gum shows highest inhibition efficiency of 43.9 % after 48 h of study at the highest concentration of additive, 5.0 g/l (see Fig. 3b). This indicates that the polymer-polymer attraction forces could not well be overcome by polymer-solvent attraction forces, due to the presence of strong intermolecular forces whose solubility is time-sensitive.

However, the inhibiting action of organic substances during metal corrosion is based on the adsorbability of their molecules, where the resulting adsorption film isolates the metal from the corrosive medium. It is observed in Fig. that the inhibition efficiency increases with increasing concentration of the xanthan gum. Due to the complex chemical composition of the xanthan gum, it is quite difficult to assign the inhibitive effect to a particular constituent.

However, it could be reasoned that the inhibitive action is a mutual effect of all the relevant adsorbable molecules present in the xanthan gum. Therefore, the adsorption of these molecules on the aluminium surface reduces the surface area available for corrosion. Consequently, in inhibited solutions, the corrosion rate is indicative of the number of free corrosion sites remaining after some sites have been effectively blocked by the adsorbed xanthan gum.

### 3.1.2 Adsorption/thermodynamic considerations

To understand the mechanism of adsorption of xanthan gum and extrapolate vital information regarding the nature of interaction between the xanthan gum and the corroding aluminium surface, adsorption isotherms are quite useful. The most frequently used adsorption isotherms are Frumkin, Temkin, Freundlich, Flory-

Huggins, Bockris-Swinkler, El-Awady and Langmuir isotherms. All these isotherms can be represented as follows [32]:

$$f(\theta, x) \exp(-2a\theta) = K_{ads} C \quad (3)$$

where  $f(\theta, x)$  is the configuration factor which depends upon the physical model and the assumptions underlying the derivation of the isotherm.  $\theta$  is the degree of surface coverage,  $C$  is the concentration of the inhibitor,  $x$  is the size

ratio,  $a$  is molecular interaction parameter and  $K_{ads}$  is the equilibrium constant of the adsorption process. Adsorption of xanthan gum is best explained by Temkin and El-Awady adsorption isotherms. The surface coverage values were fitted into Temkin adsorption isotherm which has the form

$$\exp(-2a\theta) = K_{ads} C \quad (4)$$

The parameters retain their previous meanings. The plot of surface coverage,  $\theta$  as a function of  $\ln C$  is shown in Fig. 4.

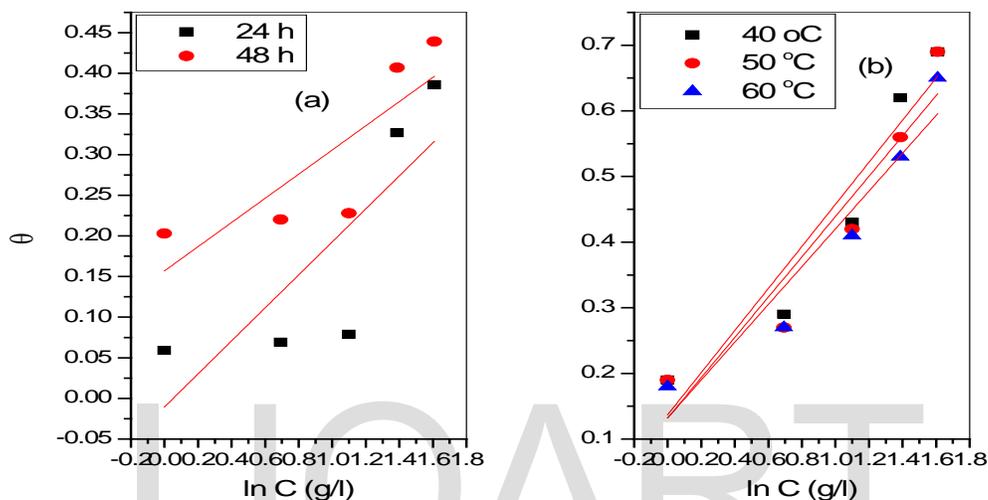


Fig. 4. Temkin adsorption isotherm plot for aluminium dissolution in 1.0 M HCl in the presence of xanthan gum as a function of (a) immersion time at 28±1 °C and (b) temperature variation.

From the plots, straight lines were obtained, suggesting that its adsorption on the aluminium surface follows Temkin isotherm. This result confirms the assumption that the corrosion inhibition of the xanthan gum is attributed to the adsorption of molecules present in the xanthan gum on the metal surface. The calculated values of molecular interaction,  $a$  and equilibrium constant of adsorption process,  $K_{ads}$  obtained from Temkin's plot is

given in Table 3. The values of  $a$  are negative showing that repulsion exist in the adsorption layer [33]. The value of  $K_{ads}$  is low suggesting that the inhibitor is physically adsorbed on the aluminium surface. Generally,  $K_{ads}$  represents the adsorption strength between the metal surface and the inhibitor. Large values of  $K_{ads}$  imply more efficient adsorption, hence better inhibition efficiency [34].

Table 3

Adsorption parameters for Temkin and Thermodynamic-Kinetic isotherms for aluminium dissolution in 1.0 M HCl in the presence of xanthan gum as a function of immersion time at 28±1 °C.

| Immersion time (h) | Temkin isotherm |           |                           | Thermodynamic-Kinetic model |                        |                           |
|--------------------|-----------------|-----------|---------------------------|-----------------------------|------------------------|---------------------------|
|                    | $a$             | $K_{ads}$ | $\Delta G_{ads}$ (kJ/mol) | $1/y$                       | $K_{ads}$              | $\Delta G_{ads}$ (kJ/mol) |
| 24                 | -2.46           | 0.95      | -9.92                     | 0.68                        | $11.20 \times 10^{-2}$ | -2.00                     |
| 48                 | -3.36           | 2.87      | -12.69                    | 1.40                        | $11.25 \times 10^{-2}$ | -6.15                     |

Table 4

Adsorption parameters for Temkin and Thermodynamic-Kinetic isotherms for aluminium dissolution in 1.0 M HCl in the presence of xanthan gum as a function of temperature variation.

| Temp. (°C) | Temkin isotherm | Thermodynamic-Kinetic model |
|------------|-----------------|-----------------------------|
|------------|-----------------|-----------------------------|

|    | $a$   | $K_{ads}$ | $\Delta G_{ads}$ (kJ/mol) | $1/y$ | $K_{ads}$ | $\Delta G_{ads}$ (kJ/mol) |
|----|-------|-----------|---------------------------|-------|-----------|---------------------------|
| 40 | -1.56 | 1.53      | -11.56                    | 0.70  | 0.32      | -7.49                     |
| 50 | -1.63 | 1.54      | -11.95                    | 0.72  | 0.30      | -7.55                     |
| 60 | -1.74 | 1.58      | -12.39                    | 0.76  | 0.28      | -7.60                     |

The surface coverage values obtained from the weight loss measurements are also fitted into the adsorption isotherm of the Thermodynamic-Kinetic model of El-Awady *et al.* [35] given by the expression

$$\log \left[ \frac{\theta}{1-\theta} \right] = \log K^i + y \log C \quad (5)$$

$\theta$  and  $C$  retain their previous meanings.  $K_{ads}$  is the equilibrium constant of adsorption and  $K_{ads} = K^i 1/y$ . Here,  $1/y$  is the number of active sites occupied by one molecule of xanthan gum (or the number of water molecules replaced by one molecule of xanthan gum). The plot of  $\log \left[ \frac{\theta}{1-\theta} \right]$  against  $\log C$  gives straight lines which approximate to the El-Awady model.

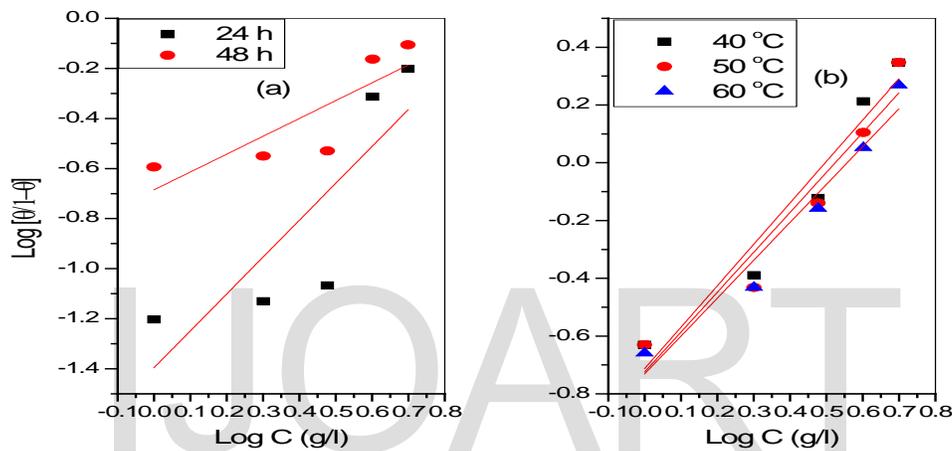


Fig. 5. Plots of Thermodynamic-Kinetic model for aluminium dissolution in 1.0 M HCl in the presence of xanthan gum as a function of (a) immersion time at  $28 \pm 1$  °C and (b) temperature variation.

The data extrapolated from the plot are given in Table. The value of  $1/y$  obtained when the system is exposed for 24 h is 0.68 indicating that one molecule of xanthan gum could not block completely one active site on the corroding aluminium surface. At the 48 h of the study, the value of  $1/y$  is more than unity indicating that one molecule of xanthan gum occupies more than one active site on the aluminium surface.  $K_{ads}$  is related to the free energy of adsorption,  $\Delta G_{ads}$  by the equation

$$\Delta G_{ads} = -RT \left[ 55.5 K_{ads} \right] \quad (6)$$

where  $R$  and  $T$  are universal gas constant and absolute temperature respectively. The values of free energy of adsorption were obtained from equation. The data are given in Table. Results obtained show that the values of  $\Delta G_{ads}$  are negative in all cases indicating the inhibitor function by physically adsorbing on the surface of aluminium. Generally, values of  $\Delta G_{ads}$  up to -20 kJ/mol

are consistent with electrostatic interaction between charged molecules and a charged metal (which indicate physical adsorption) while  $\Delta G_{ads}$  values more negative than -40 kJ/mol involves charge sharing or transfer from the inhibitor molecules to the metal surface to form a coordinate type of bond (which indicates chemical adsorption) [36].

### 3.1.3 Effect of temperature

The effect of temperature on the corrosion behaviour of aluminium in the free acid solution and in the solution containing different concentrations of xanthan gum was investigated at 40, 50 and 60 °C. The data in Table 1 indicate that the rates of corrosion in the absence and presence of the xanthan gum increased with rise in temperature, since temperature elevation usually accelerates corrosive processes. Conversely, inhibition efficiency decreased with increasing temperature as shown in Fig. 6.

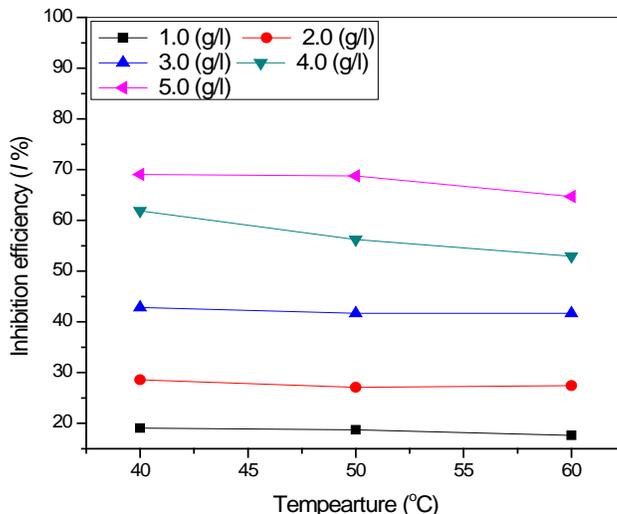


Fig. 6. Plots of inhibition efficiency versus temperature for aluminium dissolution in 1.0 M HCl solution in the presence of xanthan gum

The observed trend may be attributed to the higher dissolution rates of aluminium at elevated temperature and a possible desorption of adsorbed inhibitor due to increased solution agitation resulting from higher rates of cathodic hydrogen evolution reaction, which may also reduce the ability of the inhibitor to be adsorbed on the

metal surface. Such behaviour suggested physical adsorption of xanthan gum on the corroding aluminium surface.

In order to analyze the temperature-dependent effect of the corrosion process, the apparent activation energies ( $E_a$ ) for the corrosion process in the absence and presence of xanthan gum were evaluated from Arrhenius equation [37]:

$$\log CR = \frac{-E_a}{2.303RT} + \log A \quad (7)$$

where  $A$  is the frequency factor and other parameters retain their previous meanings. Fig. 7 represents the Arrhenius plot where  $\log CR$  is plotted against  $1/T$  for aluminium corrosion in 1.0 M HCl in the absence and presence of various concentrations of xanthan gum.

Table 5

Apparent activation energy for aluminium dissolution in 1.0 M HCl solution in the absence and presence of xanthan gum.

| System | $E_a$ (kJ/mol) |
|--------|----------------|
| Blank  | 11.09          |

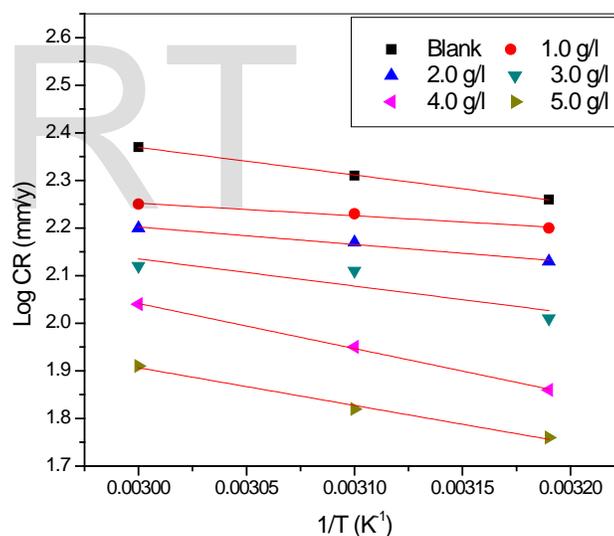


Fig. 7. Arrhenius plots for aluminium dissolution in 1.0 M HCl solution in the absence and presence of xanthan gum.

Straight lines were obtained with slope equals  $-E_a/2.303R$ . The values of  $E_a$  for the corrosion reaction in the absence and presence of xanthan gum were calculated and presented in Table 5.

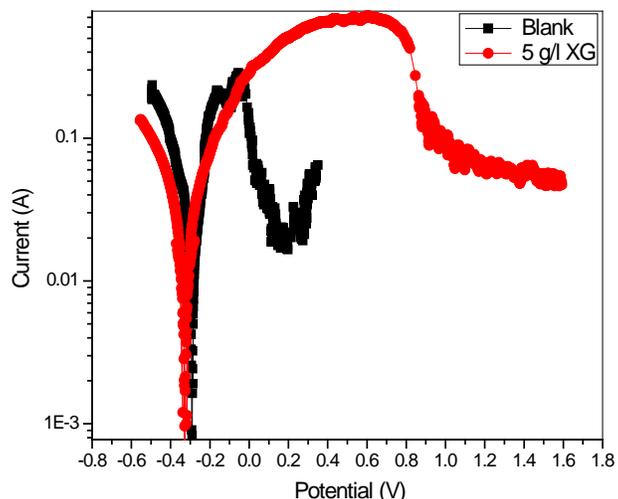
|         |       |
|---------|-------|
| 1.0 g/l | 5.02  |
| 2.0 g/l | 7.03  |
| 3.0 g/l | 10.92 |
| 4.0 g/l | 18.12 |
| 5.0 g/l | 15.16 |

From the data, a decrease in inhibition efficiency with rise in temperature, with corresponding increase in corrosion activation energy in the presence of xanthan gum compared to its value in the absence of xanthan gum, is often interpreted as being suggestive of physical adsorption, whereas the reverse effect suggests a chemical adsorption [38]. It has been suggested however, that adsorption of an organic inhibitor can affect the corrosion rate by either decreasing the available reaction area (geometric blocking effect) or by modifying the activation energy of the anodic or cathodic reactions occurring in the inhibitor free surface in the course of the inhibited corrosion process [39]. Furthermore, the inhibiting organic molecules may exist as either protonated or molecular species, depending on the nature of the chemical changes occurring to the inhibitor as well as changes to the corrodent. protonated species adsorb on cathodic sites on the metal and inhibit the hydrogen gas evolution reaction, whereas molecular species decrease the anodic dissolution of the metal [40]. Considering the positive surface charge on a corroding aluminium specimen in acidic solution, protonated species are normally poorly adsorbed. Improved adsorption should however be obtained in hydrochloric acid solution due to the tendency of chloride ions to be strongly adsorbed on the metal surface and hence facilitate physical adsorption of cation type inhibitors.

### 3.2 Potentiodynamic polarization measurements

Polarization experiments were conducted with blank and 5.0 g/l inhibited test solutions to gain insight on the effect of xanthan gum on the kinetics of anodic and cathodic reactions occurring on the aluminium electrode in 1.0 M HCl solutions. The resulting polarization curves are given in Fig. 8. It follows from Fig. 8 that the cathodic partial hydrogen evolution reaction is markedly affected by the xanthan gum, while the anodic one is slightly affected. The effect of anodic partial inhibitive reaction diminished with increasing corrosion potential whereby the effect is eliminated at corrosion potential -0.1 V. Based on the fact that  $E_{corr}$  is not altered to any significant extent, the implication is that the corrosion inhibition process is under mixed control with predominant cathodic effect. In general, the corrosion inhibition effect of xanthan gum is contributed significantly by cathodic partial inhibition reaction and also by slight reduction of anodic partial reaction. However, increase in corrosion potential, at an extent, exerted a stimulating effect on the anodic partial Fig. 8. Potentiodynamic polarization plots aluminium in 1.0 M HCl solution in the absence and presence of xanthan gum.

reaction, suggesting that the anodic dissolution reaction is the predominant reaction determining the corrosion rate of the system.



In addition, from the polarization curves of Fig. 8 for the blank acid solution and in the inhibited system, the extrapolation of Tafel straight lines allows the calculation of the corrosion current density ( $I_{corr}$ ), the corrosion potential ( $E_{corr}$ ), cathodic and anodic Tafel slopes ( $\beta_a$  and  $\beta_c$  respectively) and they are given in Table 6. The change in  $\beta_a$  and  $\beta_c$  as shown in Table 6 indicates that adsorption of xanthan gum modifies the mechanism of anodic dissolution as well as cathodic hydrogen evolution [37]. Basically, anodic polarization is the shift of anodic potential to the positive (noble) direction whereas cathodic polarization is the shift of cathode potential to the negative (active) direction. In literature [22], it has been reported that if the displacement in  $E_{corr}$  is  $> 85$  mV, the inhibitor can be regarded as a cathodic or anodic type inhibitor and if the displacement in  $E_{corr}$  is  $< 85$  mV, the inhibitor can be seen as mixed type. In this study, the displacement in the corrosion potential ( $E_{corr}$ ) in the presence of xanthan gum shifted 46.22 mV cathodically compared to the blank, which is an indication that the inhibitor acts as a mixed-type inhibitor with predominant cathodic effect.

**Table 6**

Polarization parameters for the corrosion of aluminium in 1.0 M HCl in the absence and presence of xanthan gum

| System | $E_{corr}$ (mV/SCE) | $I_{corr}$ ( $\mu\text{A cm}^{-2}$ ) | $\beta_c$ (mV) | $\beta_a$ (mV) |
|--------|---------------------|--------------------------------------|----------------|----------------|
| Blank  | -281.18             | 405.19                               | 178.80         | 80.30          |

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|            |         |        |        |       |
|------------|---------|--------|--------|-------|
| 5.0 g/l XG | -327.40 | 293.21 | 196.50 | 55.20 |
|------------|---------|--------|--------|-------|

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### 3.3 Mechanism of inhibition

In most inhibition studies, there are several reports [42-45] on the formation of donor - acceptor surface complexes between electrons of the inhibitor and the vacant *d* - orbital of metals. The first step in the sequence of action mechanism of organic corrosion inhibitors in acid media is adsorption on the metal surface, followed by replacement of pre-adsorbed water molecules, resulting to modification of a low stable metal surface in the acid medium to a more stable metal-inhibitor complex [46].

The main constituents of xanthan gum are glucose, mannose and glucuronic acid which contains  $\pi$ -electrons, O-atoms, carbonyl functions and large number of aromatic rings. In the acid solution, due to protonation of carbonyl groups (- COO -), the inhibitor molecules get adsorbed on the aluminium surface. Since the constituent molecules contain aromatic rings ( $\pi$ -electrons) and electron-releasing groups attached to these aromatic rings, the availability of  $\pi$ -electrons to get bonded to the vacant *d*-orbital of aluminium is increased. At optimum concentration of xanthan gum, the formed Aluminium-xanthan gum complex precipitates at the metal/solution interface and suppresses corrosion. On increasing the concentration of xanthan gum further, more inhibitor molecules are adsorbed and corrosion inhibition increases.

The high performance of xanthan gum at elevated temperature could be due to increased kinetic energy of the macromolecule (xanthan gum) resulting to effective adsorption of the adsorbable species. The decrease in inhibition efficiency observed with rise in temperature is due to increased randomness of the molecule at elevated temperature which results to desorption, hence decrease in inhibition efficiency.

### Conclusion

The investigated xanthan gum inhibits the corrosion of aluminium in 1.0 M HCl solution and inhibition efficiency was found to increase with increasing concentration. The inhibitive effect is attributed to adsorption of xanthan gum on the aluminium surface following Temkin and El-Awady adsorption isotherms. Temperature studies revealed that xanthan gum functioned optimally at low temperatures. This was substantiated by the values of kinetic and activation parameters derived from corrosion and inhibition processes. Polarization studies indicated that the corrosion inhibitive effect of xanthan gum is contributed significantly by cathodic partial

inhibitive reaction whereas the anodic dissolution reaction is the predominant reaction determining the corrosion rate of the system.

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