Journal of Basic and Environmental Sciences 3 (2016) 10– 24 **ISSN 2356-6388**

# Inhibition Of Ferralium Steel Corrosion in Acid Solution by NHETP

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Article Information

Received; 12 Nov. 2015
In Revised form; 28 Dec. 2015
Accepted; 28 Dec. 2015

*Keywords:*
Steel
Corrosion
Weight loss
Polarization

Abstract

The inhibitive action of inhibitor used (NHETP) on corrosion of stainless steel in 2 M HCl solution was investigated through weight loss and electrochemical techniques. Polarization measurements indicate that all the examined compounds act as a mixed inhibitor and inhibition efficiency increases with inhibitor concentration. Maximum inhibition efficiency (99%) is obtained at $5x10^{-4}$ M NHETP inhibitor. Inhibition efficiency increases in the order: NHETP > AMORPH > NMEP. Also, inhibition mechanism and thermodynamic parameters are discussed.

## 1. Introduction

The study of stainless steel corrosion phenomena has become important particularly in acidic media because of the increased industrial applications of acid solutions. As an example, the refining of crude oil results in a variety of corrosive conditions. Refinery corrosion is generally caused by a strong acid attacking the equipment surface [1]. The other important fields of application are acid pickling, industrial cleaning, acid descaling, oil-well acid in oil recovery and the petrochemical processes [2]. Among the acid solutions, hydrochloric acid is one of the most widely used agents. Due to the exposure of mild steel to corrosive environments, they are susceptible to different types of corrosion mechanisms; there-fore, the use of corrosion inhibitors to prevent metal dissolution will be inevitable. A great number of scientific studies have been devoted to the subject of corrosion inhibitors for mild steel in acidic media [3–12]. The majority of well-known inhibitors are organic compounds containing heteroatoms, such as O, N or S, and multiple bonds, which allow an adsorption on the metal surface [13]. These compounds can adsorb on metal surface and blockthe active surface sites to reduce the corrosion rate. Four types of adsorption may take place by organic molecules at metal/solution interface: (a) electrostatic attraction between the charged molecules and charged metal, (b) interaction of uncharged electron pairs in the molecule with the metal, (c) interaction of p-electrons with the metal and (d) combination of (a) and (c) [14]. However, the stability of the inhibitor film on the metal surface depends on some physicochemical characteristics of the molecule, related to its functional groups, aromaticity, possible steric effects, electronic density of donors, type of corrosive medium, structure, charge of metal surface and nature of interaction between the p-orbital of inhibitors with the d-orbital of iron [10,15].Secondly cost of corrosion: In recent years corrosion by chemical and electrochemical reactions has assumed great economic importance throughout the world. The estimated annual loss due to corrosion is enormously large. Studies worldwide have shown that the overall cost of corrosion amount to at least 2-3% of the Gross National product and that 20-25% of the cost could be avoided by using appropriate corrosion control technology [16]. In USA the cost of corrosion per year has been estimated to be over 126B (billion) dollars in 1982. The problem of preventing of metallic corrosion is extremely complex but it is of great technological and economic importance. Corrosion of metals can be controlled by taking suitable preventive measures such as painting, plating, use of expensive alloys, use of inhibitors etc. Corrosion of engineering components many times leads to the loss of production and sometimes it may be hazardous too.

Importance of ferralium SS: the large number of uses in various industrial applications, especially in the fertilizer companies where considered very important in the manufacture of phosphoric acid but steel observed that eroded because of the promise delusional presence of hydrochloric acid factors. Hence the importance of studying ferralium corrosion due to its high price is also about where it is estimated almost 30 000 dollars per ton in contrast to the unit productivity crashes also change corroded pieces.

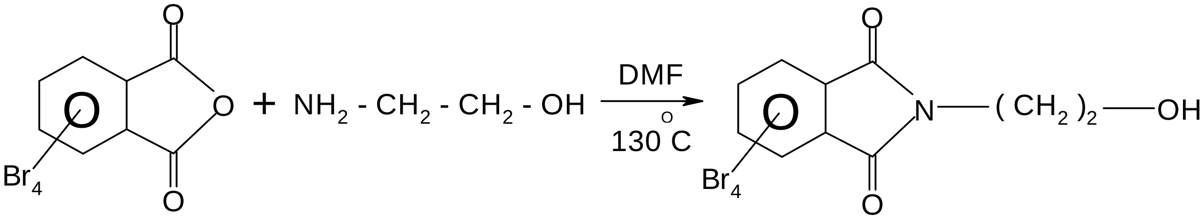
In the present work, discuss corrosion of ferralium in 2M hydrochloric acid solution and how can limited or decreases.

Fig (1): Corrosion of ferralium in agitator reactor.

## 2. Experimental

### 2.1. Preparation of NHETP inhibitor

N-Hydroxyethyltetrabromophthalimide was prepared by reaction of tetrabromophthalic anhydride with Ethanol amine in presence of DMF as solvent. The reaction occurs under reflux at 130$^{o}$C for 3hrs in oil bath. Crystallization occurs by using ethanol. M.P. arrange from (278-280$^{o}$C). The yield of recrystallized products was 70%.



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### 2.2. Solutions preparation

### a- Hydrochloric acid solution

Approximately 2M hydrochloric acid solutions were prepared by diluting the appropriate volume of the concentrated chemically pure grade acid, with double distilled water. The concentrations of the acid were checked by titration of an appropriately diluted portion with standard solution of sodium carbonate. From these stocks, concentrated solutions exactly 2M HCl were prepared by dilution with double distilled water.

### b- Inhibitor solution

100 ml stock solutions of the (NHETP)were prepared by dissolving an accurately weight of each material with concentration of ($10^{-2}$M) the appropriate volume of DMF, then the required concentrations ($5x10^{-6}$-$5x10^{-4}$M) were prepared by dilution with doubly distilled water.

### 2.3. Weight loss measurements

The reaction basin used in this method was graduated glass vessel 6 cm inner diameter and having a total volume of

250 ml. 100 ml of the test solution were employed in each experiment. The test pieces were cut into 2x2x0.5cm. They were mechanically polished with emery paper (a coarse paper was used initially and then progressively finer grades were employed), degreased in acetone [17], rinsed with bi-distilled water and finally dried between two filter papers and weighed. The test pieces were suspended by suitable glass hooks at the edge of the basin, and under the surface of the test solution by about 1cm. After specified periods of time, 3 test pieces were taken out of the test solution, rinsed with double distilled water, dried as before and weighed again. The average weight loss at a certain time for each set of three samples was taken. The corrosion rate was calculated using the following equation:

$$CR = (w_1-w_2)/at \qquad (1)$$

Where $w_1$ and $w_2$ are the weights in mg of the specimen before and after the reaction, respectively, t is the experiment time in hours and a is the surface area in $cm^2$. The inhibition efficiency IE% and degree of surface coverage θ was calculated from the following equations:

$$\%IE=[CR2-CR1/CR2]\times 100 \qquad (2)$$

$$\theta=[1-(CR\ /CR')] \qquad (3)$$

Where CR and CR′ are the corrosion rates in the presence and absence of inhibitor, respectively.

### 2.4. Polarization measurements

Electrochemical measurements were carried out in a conventional three electrode cylindrical glass cell, containing 100 ml of electrolyte at the temperature of 30 ± 1 LC. Platinum electrode was used as a counter electrode and a saturated calomel electrode (SCE) as the reference electrode. Polarization studies were conducted using computer controlled Meinsberger potentiostat/ Galvanostat with software zum PS6 remote at a scan rate of 10 mV/s. Before recording the polarization curves, the solution was deaerated for 20 min and the working electrode was maintained at its corrosion potential for 10 min until a steady state was obtained.

The inhibition efficiency IE% was calculated using the following equation:

$$\%IE= [I_2-I_1/I_2] \times 100 \qquad (4)$$

Where $I_1$ and $I_2$ are the corrosion current densities of mild steel in the presence and absence of inhibitor, respectively.

## 3. Results and discussion:

### 3.1. Weight loss measurements

The corrosion rate and inhibition efficiency for mild steel in 2 M HCl solution at $30^0$C in the absence and presence of NHETP inhibitor are given in Table 1. It is indicated that inhibition efficiency of mild steel increases with the increase of NHETP inhibitor concentration up to 99% at $30^0$C after 48hours. The increase in corrosion rate is more pronounced with the rise of temperature for the uninhibited acid solution. The presence of inhibitor leads to decrease of the corrosion rate.

The relation between time of exposure and inhibition efficiency is represented in Fig (3). Inspection of Fig (3) reveals that fast absorption of inhibitor molecules on metal this leading to high inhibition efficiency at the first hours which decreases with increasing time. This result may be interpreted on the bases of inhibitor consumption in solution at increasing time of exposure. Such consumption happens slowly in high concentration and increases with a decrease in concentration.

Table (1): Corrosion parameters of ferralium in 2M HCl solutions devoid of and containing different concentrations of NHETP inhibitor at different exposure times.

| t, h | 48 | | 96 | | 144 | | 192 | | 240 | |
|---|---|---|---|---|---|---|---|---|---|---|
| C, M | Rate (mg/cm$^2$.hr) | I.E% | Rate (mg/cm$^2$.hr) | IE% | Rate (mg/cm$^2$.hr | IE% | Rate (mg/cm$^2$.h | IE% | Rate (mg/cm$^2$.hr | IE% |
| fre | 13X10$^{-5}$ | – | 17X10$^{-5}$ | _ | 21X10$^{-5}$ | _ | 25X10$^{-5}$ | _ | 27X10$^{-5}$ | – |
| 5x10$^{-6}$ | 3.1X10$^{-5}$ | 76.1 | 6.2X10$^{-5}$ | 63.5 | 8.7X10$^{-5}$ | 58.6 | 11.2X10$^{-5}$ | 55.2 | 13.3X10$^{-5}$ | 50.7 |
| 1x10$^{-5}$ | 2.3X10$^{-5}$ | 82.3 | 4.6X10$^{-5}$ | 72.9 | 7.0X10$^{-5}$ | 66.6 | 9.4X10$^{-5}$ | 62.4 | 11.2X10$^{-5}$ | 58.6 |
| 5x10$^{-5}$ | 1.7X10$^{-5}$ | 90.7 | 3.2X10$^{-5}$ | 81.1 | 5.7X10$^{-5}$ | 72.8 | 7.9X10$^{-5}$ | 68.4 | 9.8X10$^{-5}$ | 63.7 |
| 1x10$^{-4}$ | 0.55X10$^{-5}$ | 95.7 | 1.3X10$^{-5}$ | 92.3 | 3.2X10$^{-5}$ | 84.7 | 5.7X10$^{-5}$ | 77.2 | 7.2X10$^{-5}$ | 73.3 |
| 5x10$^{-4}$ | 0.12X10$^{-5}$ | 99 | 0.54×10$^{-5}$ | 96.8 | 1.4X10$^{-5}$ | 93.3 | 2.5X10$^{-5}$ | 90 | 3.6X10$^{-5}$ | 86.6 |

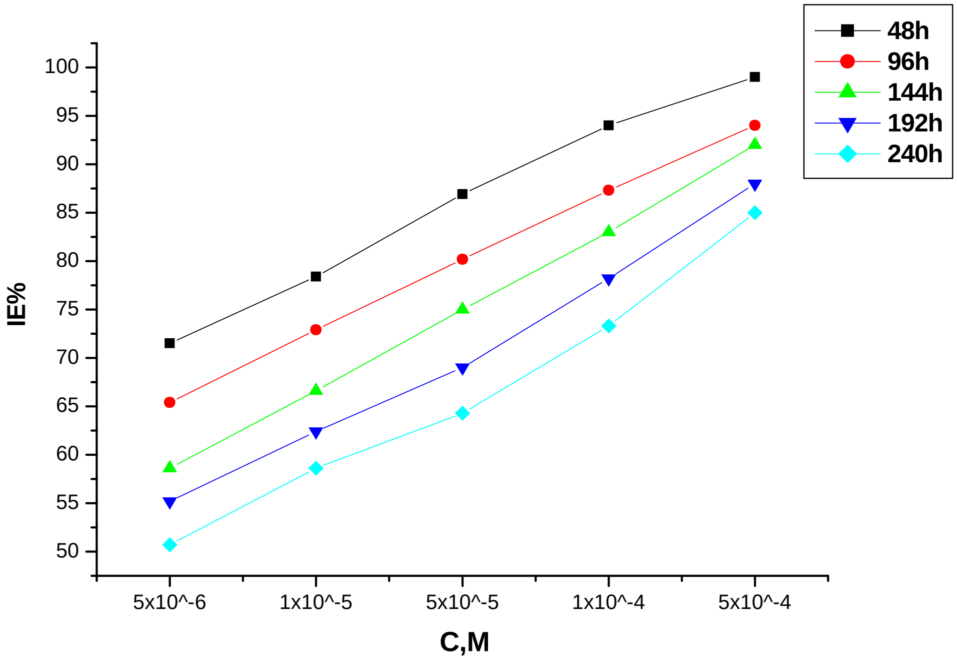

Fig (2): Relation between NHETP inhibitor concentration and inhibition efficiency.

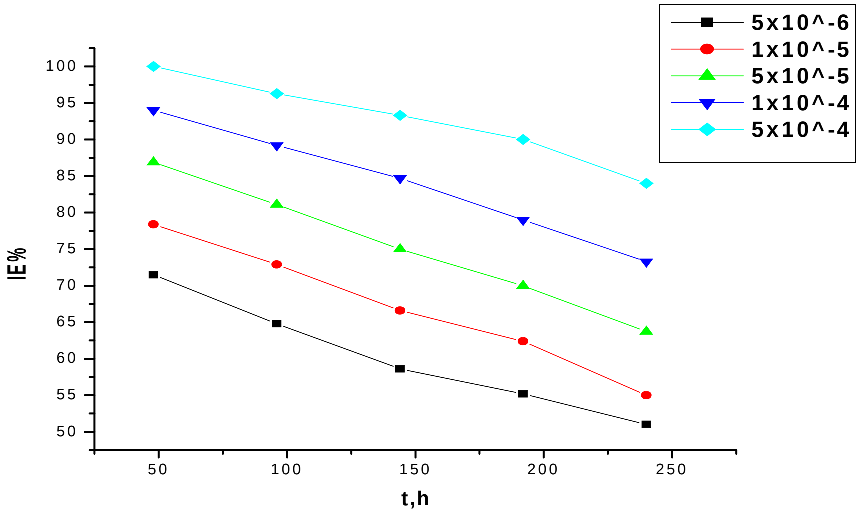

Fig (3): Relation between NHETP inhibitor exposure time and inhibition efficiency.

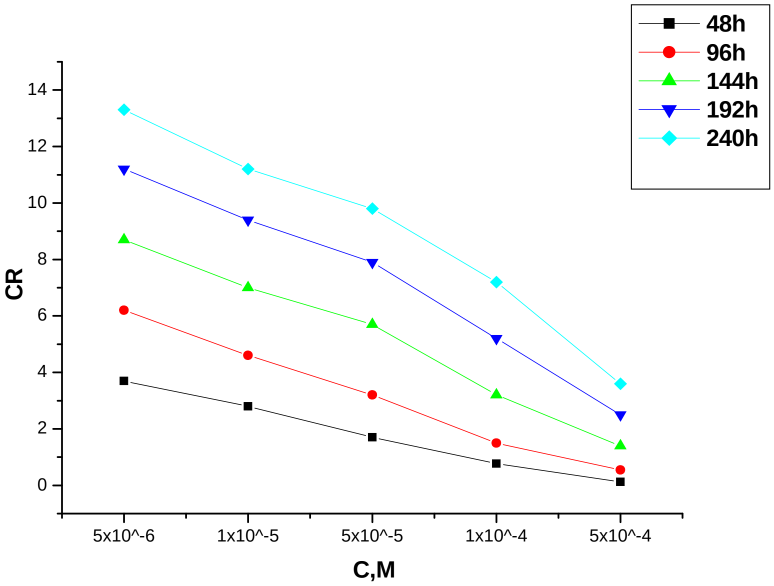

Fig (4): Relation between NHETP inhibitor corrosion rate, inhibitor, concentration.

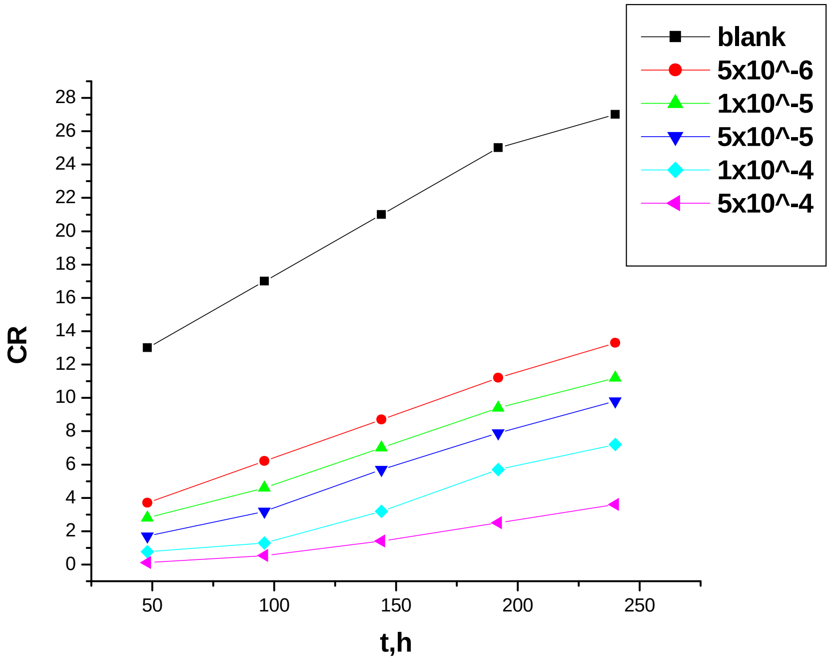

Fig (5): Relation between NHETP inhibitor corrosion rates, time.

### 3.2. Polarization measurement

The potentiodynamic polarization curves of ferralium in 2M HCl in absence and presence of of various concentrations of *NHETP* inhibitor is shown in Fig (6). The corrosion kinetic parameters such as corrosion potential ($E_{corr}$), corrosion current density ($I_{corr}$), anodic Tafel slope ($\beta_a$) and cathodic Tafel slope ($\beta_c$) deduced from the curves are given in Table (2).

Inspection of Fig (6) reveals that both the anodic and cathodic polarization curves shift toward less current densities values upon addition of the extract. This result suggests the inhibitive action of *NHETP* inhibitor toward ferralium corrosion in the acidic medium.

Several observations, due to addition of the inhibitor, could be recognized from the data of Table (2):

i. The corrosion potential does not affected by the addition of the inhibitor.

ii. The corrosion rate decreases and the inhibition efficiency increases with increasing inhibitor concentration. Upon increasing the inhibitor concentration in the bulk solution the number of molecules adsorbed on ferralium surface increases leading to increase in the inhibition efficiency.

iii. There is almost no change in both anodic and cathodic Tafel constants upon addition of increasing concentrations of the inhibitor. This result indicates that the addition of extract does not affect the mechanism of ferralium dissolution. Moreover, these findings lead to conclusion that the extract acts as mixed type inhibitor. This type of inhibitors acts by adsorption on both anodic and cathodic sites on the metal surface and thus retards both the anodic and cathodic reactions. This behavior results in decreasing the corrosion rate of the metal.

iv. The inhibition efficiency increases with increasing *NHETP* inhibitor concentration its value increases up to 92% in presence of $5x10^{-4}$ M of the inhibitor.

Table (2): Corrosion parameters of ferralium in 2 M HCl solutions devoid of and containing different concentrations of.*NHETP* inhibitor.

| C, M | $E_{corr}$- (mv) | $B_a$ mv /Decade | $B_c$ mv /Decade | $I_{corr}$ (mA) | IE % | θ |
|---|---|---|---|---|---|---|
| free | 360 | 102 | 141 | 0.320 | ------ | ------ |
| $5X10^{-6}$ | 407 | 89 | 104 | 0.085 | 73 | 0.73 |
| $1X10^{-5}$ | 390 | 110 | 103 | 0.066 | 79.3 | 0.79 |
| $5X10^{-5}$ | 403 | 74 | 125 | 0.059 | 81.5 | 0.81 |
| $1X10^{-4}$ | 364 | 91 | 119 | 0.052 | 83.7 | 0.83 |
| $5X10^{-4}$ | 390 | 92 | 110 | 0.048 | 85 | 0.85 |

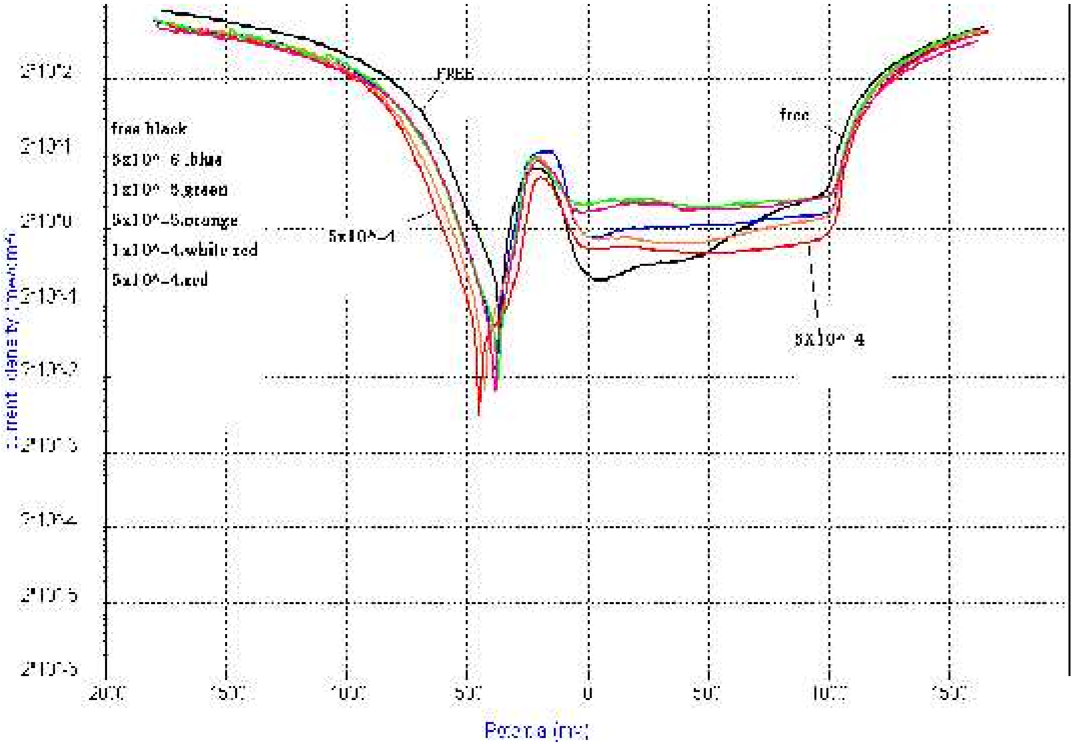

Fig (6): Polarization curves of ferralium in 2 M HCl in absence and presence of various concentrations of *NHETP* inhibitor.

### 3.3. Effect of temperature measurements:

The effect of temperature (in the range of 303 – 343 K), on the corrosion of ferralium in 2M HCl solutions devoid of and containing 5x10$^{-4}$M of the three tested inhibitors was studied using potentiostatic polarization. Table (3) contains the different corrosion parameters which determined from the polarization curves. Inspection of Table (3) reveals that:

i. In free acid solution, the corrosion potential shifts slightly to less negative potential as the temperature is increased.
ii. In free acid solution, both anodic and cathodic Tafel constants remain almost constant at all tested temperatures.
iii. The corrosion rate of ferralium, in free and inhibited acid solutions, increases as the temperature is increased.
iv. In the presence of inhibitors, increasing temperature has almost no effect on the corrosion potential and Tafel constants.
v. As the temperature increases the inhibition efficiencies of all tested extract slightly decreases.

Table.(3): Corrosion parameters of ferralium in 2M HCl solutions devoid of and containing 5x10$^{-4}$ M of NHETP inhibitor at different temperatures.

| medium | Temp. K | $-E_{corr}$ (mv) | $B_a$ mv /Decade | $B_c$ mv /Decade | $I_{corr}$ (mA) | IE % | θ |
|---|---|---|---|---|---|---|---|
| 2M HCL | 303 | 360 | 102 | 141 | 0.320 | --- | --- |
| | 313 | 373 | 130 | 170 | 0.650 | | |
| | 323 | 381 | 210 | 211 | 1.35 | | |
| | 333 | 379 | 170 | 230 | 2.160 | | |
| NHETP | 303 | 372 | 63 | 125 | 0.025 | 92 | 0.920 |
| | 313 | 398 | 125 | 175 | 0.055 | 91.5 | 0.915 |
| | 323 | 390 | 140 | 217 | 0.160 | 88.1 | 0.881 |
| | 333 | 370 | 214 | 247 | 0.320 | 85.2 | 0.852 |
| | 343 | 401 | 240 | 254 | 0.520 | 80.2 | 0.802 |

The corrosion reaction can be regarded as an Arrhenius-type process which follows the equation:

$$\log I_{corr} = \log A - \frac{E_a}{2.303\,RT} \quad (5)$$

where$I_{corr}$ represents the rate of corrosion reaction, $A$ is Arrhenius factor and $E_a$ is the apparent activation energy of the corrosion reaction. Plotting of log $I_{corr}$ versus 1/T gave straight lines, as shown in Fig (7). The values of apparent activation energies for corrosion reactions of ferralium in different media are calculated from the slopes of these lines and represented in Table (3) Other activation parameters were calculated using the transition state equation:

$$\log \frac{I_{corr}}{T} = \log \frac{R}{hN} + \frac{\Delta S^*}{2.303\,R} - \frac{\Delta H^*}{2.303\,RT} \quad (6)$$

R is the universal gas constant (8.314 J/mol.K), $N$ is the Avogadro's number (6.02 x 10$^{23}$), $h$ is the Plank's constant

($6.62 \times 10^{-34}$ $m^2$ kg /s) where $\Delta S^*$ where and $\Delta H^*$ are the entropy and the enthalpy changes of activation corrosion energies

for the transition state complex, respectively. Plotting log ($I_{corr}/T$) versus 1/T gives straight lines (Fig 8) from which the activation parameters are determined and represented in Table (3).

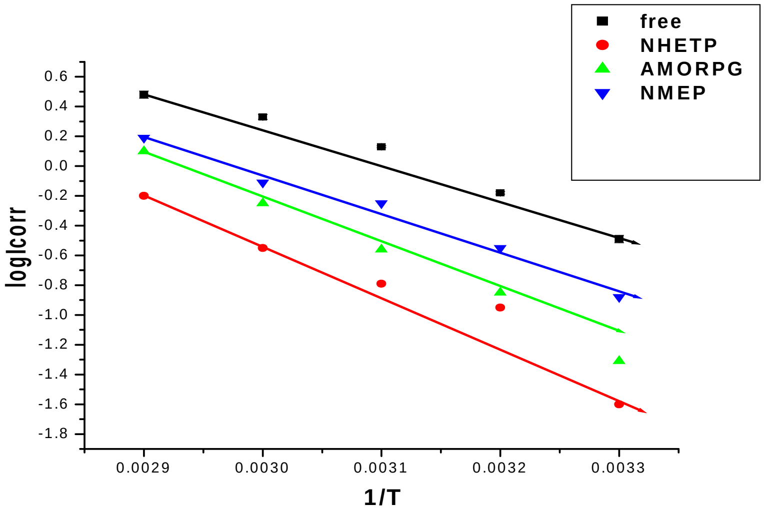

Fig (7): Arrhenius plot for corrosion of ferralium in free and inhibited 2 M HCl solutions.

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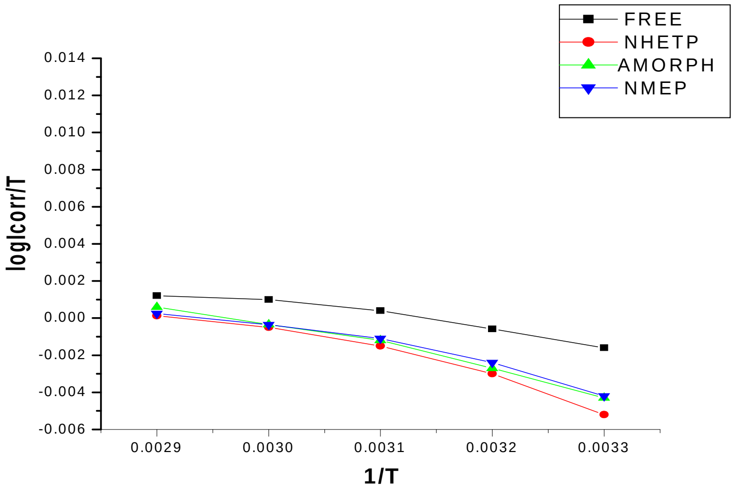

Fig (8): Transition state plot for corrosion of ferralium in free and inhibited 2M HCl solutions.

The change in the activation free energy ($\Delta G^*$) of the corrosion process can be calculated at 303K by applying the famous equation:

$$\Delta G^* = \Delta H^* - T\,\Delta S^* \qquad (7)$$

The obtained $\Delta G^*$ values was also listed in Table (4).

Table (4): Activation parameters of ferralium corrosion in free and inhibited 2M HCl solutions.

| Medium | *Ea*<br>*kJ/mol* | $\Delta H^*$<br>*kJ/mol* | - $\Delta S^*$<br>*kJ/mol K* | $\Delta G^*$ (303K)<br>*kJ/mol* |
|---|---|---|---|---|
| Free acid | 4.46 | 42.5 | 0.28 | 127.34 |
| *NMEP* | 4.86 | 53 | 0.30 | 143.9 |
| *AMORPH* | 5.20 | 50.5 | 0.29 | 138.37 |
| *NHETP* | 5.57 | 64.7 | 0.33 | 164 |

According to the data recorded in Table (4) the following discussion can be written:

i. The results show positive sign of $\Delta H^*$, reflecting the endothermic nature of the corrosion process.
ii. . Inhibitor species are physically adsorbed on the metal surface.

As observed, the trend of (*E*a) for the studied inhibitors is not the same with that obtained from inhibition efficiency. The lower activation energy for *NMEP* as compared to that of (*T*). *NHETP or NMEP* may be explained according to Riggs and Hurd [18], as they stated that at higher level of surface coverage the corrosion process may proceed on the adsorbed layer of inhibitor and not on the metal surface leading to a decrease in the apparent activation energy and in some cases becomes less than that obtained in the absence of inhibitor.

iii. The negative values of $\Delta S^*$ pointed to a greater order produced during the process of activation. This can be achieved by the formation of activated complex represents association or fixation with consequent loss in the degrees of freedom of the system during the process.

iv. The values of $\Delta G^*$ were positive indicating that the activated complex was not stable and the probability of its formation decreased somewhat with rise in temperature. So, the increase in the rate of corrosion with rise in temperature can be attributed to large number of corrosion species passing into an activated state with a less stable configuration [19]. However, $\Delta G^*$ values for the inhibited systems were less positive than that for the uninhibited systems revealing that in case of inhibitor addition the activated corrosion complex becomes more stable as compared to its absence.

This correlation can be treated as the isokinetic relationship, where the slope represents the isokinetic temperature. The slope of the straight line is 125 K, which is much lower than the experimental temperature. This indicates that the corrosion reaction is under activation-control, where the addition of the studied extracts plays an important role in reducing the corrosion rate but without changing the corrosion mechanism as indicated by the observed parallelism between $\Delta H^*$ and $\Delta S^*$ values.

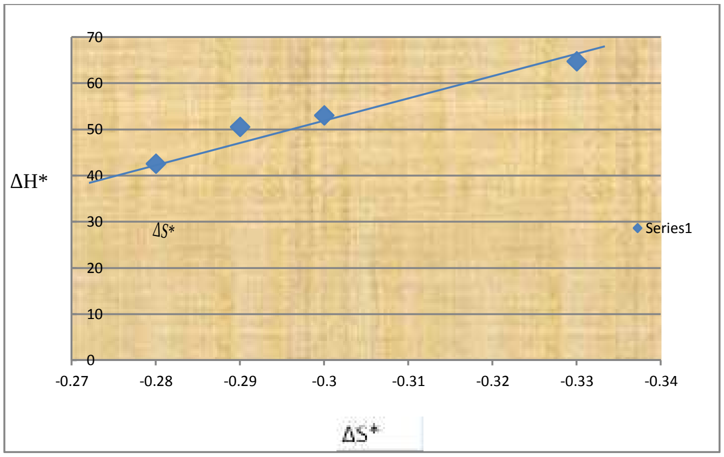

Fig (9): Variation of ΔH* with ΔS*.

### 3.5. adsorption isomerism:

The adsorption of a component *j* in a given system depends on temperature *T* and on the component's concentration, $C_j$, in the bulk phase. The overall adsorption equation can be written as $Aj = f(T, C_j)$ [20].

The relation between adsorption and the adsorbate's bulk concentration (or pressure, in the case of gases) at constant temperature is called the *adsorption isotherm*; the relation between adsorption and temperature at constant concentration is called the *adsorption isobar*. From the shape of the adsorption isotherms, the adsorption behavior can be interpreted. In the case of monolayer adsorption, the isotherms are usually written in the form

$\theta_j = f(C_j)$. (The subscript *j* is dropped in what follows)

***Henry Isotherm*** In the simplest case, the degree of surface coverage is proportional to the bulk concentration:

$\theta = KC$

An analogous law was established in 1803 by W. Henry for the solubilities of gases in water; hence, this expression is called the *Henry isotherm*. The adsorption coefficient *K* (unites $dm^3$/mol) depends on the free energy of adsorption ($-\Delta G^0_{ads}$):

$$K = K^0 exp\left(\frac{-\Delta G^0_{ads}}{RT}\right) \qquad (8)$$

$$logK = logK^0 - \left(\frac{\Delta G^0_{ads}}{RT}\right) \qquad (9)$$

The Henry isotherm is valid for low surface coverages (e.g., at $\theta < 0.1$).

***Langmuir Isotherm*** At higher values of θ, when the number of free sites on the surface diminishes, one often observes relations of the form:

$$\theta = KC\left(\frac{1}{KC+1}\right) \qquad (10)$$

or

$$\frac{\theta}{(1-\theta)} = KC \qquad (11)$$

At low values of the bulk concentration ($KC << 1$) the degree of surface coverage is proportional to this concentration, but at high values it tends toward a limit of unity. This equation was derived by Irving Langmuir in 1918 with four basic assumptions:

(1) The adsorption is reversible.

(2) The number of adsorption sites is limited, and the value of adsorption cannot exceed $A^0$.

(3) The surface is homogeneous: all adsorption sites have the same heat of adsorption and hence, the same coefficient $K$.

(4) No interaction forces exist between the adsorbed particles. The rate of adsorption is proportional to the bulk concentration and to the fraction (1 - θ) of vacant sites on the surface: $v_a = k_a C (1 - \theta)$, while the rate of desorption is proportional to the fraction of sites occupied: $v_a = k_d\theta$. In the steady state these two rates are equal. With the notation $k_a/k_d = K$.

The test of the Langmuir isotherm is that plots of $\theta/(1-\theta)$ vs. $C$ produce a straight line. Another test of the Langmuir adsorption isotherm follows from rearranging the above equation as:

$$\frac{C}{\theta} = \frac{1}{K} + C \qquad (12)$$

A plot of $\frac{C}{\theta}$ vs. $C$ will produce a straight line of unit slope if the Langmuir isotherm applies.

***Temkin Isotherm*** Numerous departures of the experimental data from the Langmuir isotherm can be explained in terms of insufficient arguments for the third and fourth assumptions. Temkin examined the case of uniform surface inhomogeneity where the heats of adsorption associated with different sites are different. He assumed a linear decrease in the free energy of adsorption with coverage:

At intermediate coverages (0.3 < θ < 0.7), Temkin adsorption isotherm equation is:

$$\exp(-2a)\theta = KC \qquad (13)$$

or

$$\theta = \frac{2.303}{x}\log K + \frac{2.303}{x}\log C \qquad (14)$$

where$x$ = (-2a) and (a) is the molecular interaction parameter which is positive if attraction forces exist between the adsorbed molecules and negative in case of presence of repulsion forces between them.

This equation is called the *logarithmic Temkin isotherm*. Thus, a test of the Temkin adsorption isotherm is that, a plot of the surface coverage ($\theta$) vs. the logarithm of inhibitor concentration (log $C$) gives a straight line over a portion of the plot.

***Frumkin Isotherm*** In 1928, Frumkin derived an equation for interaction between the adsorbed particles. Mutual attraction leads to an increase in the free energy of adsorption, whereas repulsion leads to a decrease. Quantitatively, these effects depend on the degree of surface coverage and can be written as $(\Delta G_{\mathrm{ads}})_\theta = (\Delta G^o_{\mathrm{ads}}) - f_{\mathrm{int}}RT\theta$, where $f_{\mathrm{int}}$is an interaction factor that has positive values when there is repulsion, and negative values when there is attraction between the particles (often, the attraction constant $\alpha \equiv - f_{\mathrm{int}}/2$ is used instead of the factor $f_{\mathrm{int}}$). As a result, an isotherm of the form:

$$\frac{\theta}{(1-\theta)}\exp\left(f_{\mathrm{int}}\,\theta\right) = KC \qquad (15)$$

is obtained. At values of $f_{\mathrm{int}} \geq 5$ and intermediate degree of coverage (0.3 < θ < 0.7), this equation practically coincides with the equation of the Temkin isotherm.

Trials were made to find the adsorption isotherm which been followed by the used inhibitors to inhibit ferralium corrosion in HCl solution. All the used inhibitors give straight lines upon application of Langmuir adsorption isotherm. The values of surface coverage (θ) used here were obtained from the results of the weight loss technique. However, the slopes of these straight lines were not unity indicating a presence of some kind of interaction between the adsorbed molecules. It was found that all the used extracts follow Temkin adsorption isotherm. Fig (10) represents the relationship between logarithm of extract concentration (expressed in M) and the surface coverage. Straight lines were obtained indicating a fitting of Temkin isotherm. According to Temkin equation, the slope of every line equals to (2.303RT/a) and its intercept equals to (2.303RT/a) log K'.

The Temkin adsorption parameters ($a$) and ($K$) were calculated and represented in Table (5). Table (5) contains also the values of the standard free energy of adsorption ($\Delta G^o_{\mathrm{ads}}$) calculated using the equation:

$$\log K' = -\log C_{H_2O} - \frac{\Delta G^o_{ads}}{2.303\,RT} \qquad (16)$$

It is not easy to define the compound in the extract responsible for the inhibition process. The inhibition process of the extract is a result of a synergetic action of its whole constitutes. Accordingly, it is impossible to use the molarity to express the extract concentration.

Inspection of the data of Table (5) reveals that the drawn lines have very high correlation coefficient ($R^2$) indicating that all the studied extracts obey Temkin adsorption isotherm. Moreover, the values of the free energy of adsorption are negative for all tested extracts indicating that the adsorption of the extracts constituents is a spontaneous process. However, there is no a great differences between the adsorption free energies of the used extracts.

Table (5): The Temkin adsorption isotherm parameters

| inhibitor | Molar mass g/mol | $R^2$ | logK | - a | $-\Delta G^o_{ads}$ $kJ.mol^{-1}$ |
|---|---|---|---|---|---|
| *NHETP* | 129 | 0.95 | 4.7 | 19 | 37.38 |
| *AMORPH* | 141 | 0.96 | 5.01 | 20 | 39.1 |
| *NMEP* | 259 | 0.95 | 5.72 | 23 | 43.2 |

In order to go closer to the true values of the free energies of adsorption, the molarity of the major component is used as representative for inhibitor. Looking at the structures of these compounds it reveals that they have, more or less, comparable molecular mass. Therefore, it may be a way to approach the true value of adsorption free energy is calculate the extract concentration as if it contains only its compound. Thus, the Temkin isotherms were redrawn using the major component molecular mass for each inhibitor and represented in Fig (10).

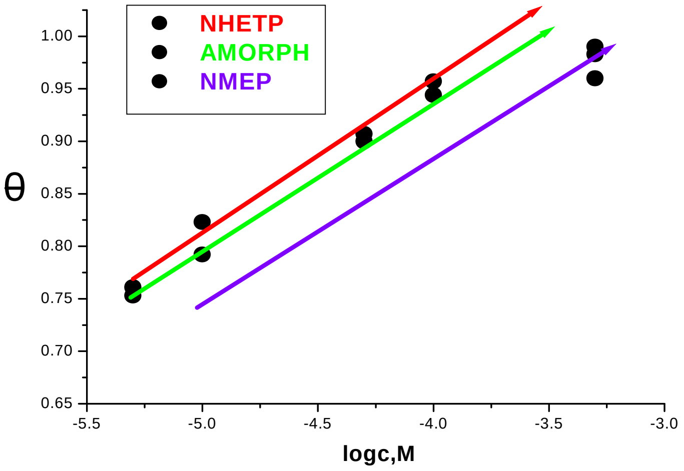

Fig (10): Temkin adsorption i isotherm drawn using molar concentrations of the major components of the different inhibitors in 2M HCl solution.

The Temkin adsorption isotherm parameters obtained from these relations are represented in Table (5). Inspection the data in Table (5) reveals that the values of parameter (a) are identical as those in Table (5).This finding is expected since the use of any concentration unit will yield the same slope value from which (a) is calculated. On the other hand, the values of energy of adsorption are higher than those obtained in Table (5). However, the adsorption free energies calculated from both methods indicate that the adsorption of the inhibitor component is physical in nature. Moreover, the negative sign of the parameter (a) suggests that there is a repulsion force between the adsorbed molecules. The presence of such forces weakens the adsorption process and consequently decreases the inhibitive effect of the adsorbed molecules.

## Conclusions:

- (NHETP) acts as corrosion inhibitor of ferralium stainless steel in 2 M HCl solution.
- Iinhibition efficiency increases with increasing concentration.
- Iinhibition efficiency decreases with increasing temperature.
- The (NHETP) acts as mixed type inhibitor.
- The inhibitor used acts by adsorption on the surface of the metal layer composed isolate the metal surface from the center-corrosive.

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