

USING METHYL UREA AS INHIBITOR FOR THE CORROSION OF CARBON STEEL IN 1M HYDROCHLORIC ACID MEDIUM

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Abstract

The corrosion behaviour of carbon steel in 1M HCl solution containing various concentration of methyl urea range (10^{-3} → 5×10^{-2})M at temperature range (285-313)K was investigated. The corrosion inhibitive action of methyl urea on carbon steel was studied using weight loss measurement and atomic absorption analysis to find the amounts of dissolved metal in acidic solution in presence and absence of methyl urea. The results showed that urea caused protection efficiency reached to 82% when (10^{-3})M methyl urea concentration was used. The coverage (θ) of metal surface by methyl urea could be obtained from the rate of corrosion in the presence and absence of methyl urea in the acid solution. Results obtained by gravimetric and atomic absorption are in good agreement. A linear relationship was found to exist between the value of (C/θ) and the corresponding methyl urea concentration (C) indicating that the inhibition action occurs via adsorption mechanism. Changes in the free energy, enthalpy and entropy associated with methyl urea adsorption have been determined. Apparent energies of activation have been calculated for the corrosion process of iron in the acid from corrosion rates and Arrhenius plots.

الخلاصة

تم دراسة السلوك التآكلي للحديد الكربوني في محلول 1 مولاري من حامض الهيدروكلوريك على مدى من التراكيز المختلفة في مثيل يوريا كمثبط للتآكل تراوحت بين (3-10-2-5×10) مولاري بمدى من درجات الحرارة تراوحت بين (285-313) كلفن. وتمت هذه الدراسة باستخدام تقنيتين مختلفتين هما 1-تقدير الوزن المفقود للحديد الكربوني نتيجة التآكل، 2- تقدير الحديد الذائب في محلول الحامض بطريقة الامتصاص الذري وبوجود وغياب المثيل يوريا في المحلول كمثبط.

وقد اظهرت النتائج ان المثيل يوريا خفضت عملية التآكل الى 82% عند تركيز 3-10 مولاري وامكن ايجاد مقدار تغطية (θ) سطح النماذج بالمثيل يوريا من حساب سرعة التآكل بوجود وغياب المثيل يوريا في الوسط الحامضي. وتبين ان هناك تقارب بين القيم المستحصلة بالطرق الوزنية والطيفية وقد اظهرت الدراسة وجود علاقة خطية بين قيم (C/θ) وتراكيز (C) للمثيل يوريا المناظرة لها موضعاً حدوث فعل التثبيط من خلال عملية الامتزاز. وتم دراسة التغير في قيمة الطاقة الحرة والانتالبي والانتروبي المرافقة لامتزاز المثيل يوريا على سطح المعدن وتم ايجاد طاقة التنشيط لعملية التآكل وذلك من قياسات سرع التآكل في الدرجات الحرارية المختلفة وعلاقة ارينيوس.

Introduction

The dissolution behavior of carbon steel in acidic and nearly neutral media was known to be inhibited by nitrogen and sulfur containing organic compounds[1-2].

Such compounds contain electron-donating groups that decrease the corrosion rate by increasing the hydrogen overvoltage on the corroding metal [3].

The use of nitrogen containing compounds as corrosion inhibitors is widespread. These

compounds can bind to metal surfaces by electron transfer to form a coordinated bond and hence iron effective inhibition [4].

Polarization measurements on the organic compounds indicate that they are cathodic inhibitors[5]. Methods of comparing the inhibition efficiencies of surfactants are numerous and involve, among others, weight loss determination, electrode potential measurements, construction of electrocapillary curves depression of polarographis maxima, determination of electrode reaction parameters and determination of elements dissolved by ultraviolet-visible absorption spectroscopy[6]. The corrosion inhibition of carbon steel have been observed potentiostatically by many workers[7], however, most of the interests of these workers mainly were related to the effect of the type of functional groups of the organic inhibitors and the best percentage of inorganic compounds to each complete protection.

The inhibiting action of some urea compound on the corrosion behavior of (410) steel in 1M H₂SO₄ was understood using weight loss measurements, the adsorption followed the langmuir adsorption isotherm.

The best protective properties from sols consisting of three SiO₂ layers with nanosilica and three SiO₂ layers without nanosilica [8].

The kinetics and thermodynamics of the corrosion process and the actual role of certain chemicals in corrosion inhibition are among the aspects which attracted relatively little attention. In the present work has therefore been planned to investigate the weak corrosion behaviour of carbon steel specimen in 1M HCl. The research also involved the use of methyl urea as an inhibitor for the acid corrosion of carbon steel. The effect of the inhibitor on the corrosion rate has been estimated using both weight loss and atomic absorption spectroscopy measurement. Inhibitors are widely used to control the corrosion of metallic materials and function one or more of the following mechanisms [9]:

- 1- by adsorption on the surface of according material.
- 2- by changing the corrosion characteristics of the environment.
- 3- by inducing the function of a protective layer of corrosion product.

Experimental

Low carbon steel AISI 5135 (obtained from ministry of industry) had the following

composition as revealed by emission spectroscopic analysis:-

Element	C	P	S	Si	Mn	Cr
wt. %	0.38-0.44	0.035	0.035	0.15-0.35	0.5-0.8	0.9-1.2

were used for the measurement of the corrosion rate. All test pieces having thickness about 7mm and diameter 17 mm.

Specimens were abraded in sequence under run tap water by using the following emery paper grades; 220, 320, 400 and 600, washed with run tap water followed by distilled water, dried with cotton, immersed in ethyl alcohol and dried, immersed in acetone, they were left to dry over silica gel before use.

Each experiment was carried out with 20ml of the corroding solution and with fresh test piece. The temperature was measured to (± 0.1)°C. All chemical were used of A.R. quality and were employed without further purification. 1M hydrochloric acid solution was prepared by analytical dilution from stock solution.

After each test, specimens were washed with running tap water, cleaned with brush to remove the weakly with adherent corrosion scale, rinsed with distilled water, swabbed with cotton wool soaked in 5% H₂SO₄ containing 0.011 wt.% thiourea [10] to remove all adherent corrosion products. Then specimens were washed with tap water followed by distilled water and dried.

Then the specimen were rinsed with analar benzene, dried with Klenex tissue followed by rinsing with analar acetone, dried with Kleenex tissue, then left to dry and weighed to the 4th decimal of gram. In order to analyse elements dissolved in 50 solutions after weight loss tests, atomic absorption spectroscopy was used with acetylene-air flame, and the wavelengths were employed was 2483A° for Fe.

Results

Weight Loss Measurements

The corrosion of carbon steel in 1M HCl solution containing various methyl urea concentration studied by weight loss measurements at various temperature (285-313)K at immersion period of 2h. The corrosion rate of carbon steel is determined by using the relation.

$$R_{(w) \text{ loss}} = \Delta m / \Delta t \dots\dots(1) \text{ mg.cm}^{-2}.\text{hour}^{-1}$$

$$R_{(w) \text{ A.A}} = \Delta m / \Delta t \dots\dots(2)$$

Where Δm is the mass loss of the metal in the acidic solution and Δt is the immersion period. The corrosion rate result is shown in Table (1).

Corrosion Protection

The percentage protection efficiency %P is calculated using the relationship [11]:

$$\%P = \frac{(R_{wo} - R_{winh})}{R_{wo}} \times 100 \quad \text{.....(3)}$$

Where $R_{(winh)}$, R_{wo} are the corrosion rate of carbon steel in presence and absence of methyl urea. Table (2) shows the percent protection efficiency (P%) using the weight loss and atomic absorption measurements. The protection efficiency increase with temperature increase at low concentration of methyl urea as shown in Figure (1a,b).

There was an initial sharp increasing in P% Figure.(2a) subsequent to the first additions of the inhibitor (1.0 to 10 mM) remaining there after constant over concentration from (25 to 50 mM).

P% values were plotted at different methyl urea concentrations (Figure2a,b) and were found dependent of temperature.

The temperature effect was significant in the presence of high concentration of methyl urea and P% increased with temperature increasing. This result may be interpreted by many authors⁽⁵⁾ for the following reasons: temperature is a predominant factor in the formation of a protective layer at the metallic surface formed by metal inhibitor interaction.

The P% calculated from weight loss and atomic absorption measurements varied with methyl urea concentration at temperature varying (285-313)K Figure (2 a,b).

Adsorption and Surface Coverage

The degree of coverage θ_{inh} of the carbon steel surface by methyl urea could be calculated using the equation:

$$\theta_{inh} = \frac{(R_{wo} - R_{(winh)})}{R_{wo}} \quad \text{.....(4)}$$

The θ_{inh} values shown in Table (2). The maximum values of θ at 313K (0.7169) but were relatively lower at 307K (0.16633).

The adsorption behavior of methyl urea on carbon steel surface, can be described as indicated in Figure(3 a,b) where linear relationship is shown to exist between the values of (C/θ) and the corresponding urea concentration (C). Such relationships suggest that methyl urea acts as corrosion inhibitor via

adsorption on carbon steel surface. The type of adsorbate-adsorbent interaction follows langmuir adsorption isotherm which may be represented as [12]:

$$C/\theta = (1/b) + C \quad \text{.....(5)}$$

Where $(1/b)$ is the intercept of each line on the (C/θ) axis when methyl urea concentration (C) approaches zero. The constant b in equation (5) may be considered as an equilibrium constant which could be defined by the following equation⁽¹³⁾:

$$b = a \exp(q/RT) \quad \text{.....(6)}$$

Where q is the heat of methyl urea adsorption on carbon steel surface.

The per-exponential factor (a) in equation (6) includes several other terms [14] relating to condensation and adsorption processes. The values of b which have been derived from the intercepts of the plots in Figure(4) are described in Table (3).

Thus there is a smooth increase in the values of b with the rise of temperature from (285-313)K.

A plot of $\log b$ against $(1/T)$ (equation.6) should produce a straight line provided (q) and (a) remained independent of temperature as indicated in Figure.(4). The heats of adsorption derived from the slopes of two lines were respectively 23.159 and 12.472kJ.mol⁻¹. Thus the endothermic adsorption process has occurred and it was in full agreement with the substantially higher protection efficiencies which have been observed as indicated in Figure(1,2).

The term b, defined by equation (6) is equilibrium constant of the adsorption-desorption processes for methyl-urea-carbon steel system which may be represented as follows:

$$b = \exp(-\Delta G_a/RT) \\ = \exp(\Delta S_a/R) \exp(-\Delta H_a/RT) \quad \text{.....(7)}$$

where ΔG_a , ΔS_a , ΔH_a are respectively the changes in the free energy, entropy and enthalpy of adsorption of methyl urea on carbon steel specimen. Values of ΔH_a in equation (7) may be considered to be those derived previously from the plots of Figure(4) using the values of b and ΔH_a . It was possible to estimate the corresponding values of ΔS_a and ΔG_a at each of

the four temperatures in the range (285-313)K and the resulting data are presented in Table (4). The negative value of ΔG means that the adsorption of methyl urea extract on carbon steel surface is spontaneous process, and furthermore the negative values of ΔG also show the strong interaction of inhibitor molecule into carbon steel surface[7].

The average values of ΔG_a were obtained from the two methods are (-16.907, -15.036 kJ.mol⁻¹). These results indicate that methyl urea adsorption on the carbon steel specimen becomes more favourable with the rise of temperature for (285-313)K. This may account for the higher protection efficiencies of methyl urea over such temperatures. The value of ΔS gives relatively greater degrees of freedom for the adsorbed molecules in the surface with a consequent enhancement in the rate of methyl urea adsorption.

This means the formation of an ordered stable layer of inhibitor on the carbon steel surface.

Kinetic Aspects

The rate (R) of corrosion of carbon steel in 1M HCl solution in the absence and the presence of methyl urea, increased with temperature over the range 285-313K. This is reflected in the variation of (log R) values, for both the blank (absence of methyl urea) and various solutions of methyl urea, with the reciprocal of temperature (1/T) in the manner depicted in Figure(5). The linear relationship observed between the values of (log R) and (1/T) Figure(5) confirms the Arrhenius type equation [11]:

$$R = A \exp(-E/RT)$$

Where E is the apparent energy of activation for the corrosion process and A is the pre-exponential factor. Values of E could thus be derived from the slopes of Figure(5). Fig.(6) shows the resulting values of E_a as a function of methyl urea concentration in 1M HCl solution.

There was initial sharp decreases in E_a values (Figure.(6)) at methyl urea concentration 1×10^{-3} mM. Increasing of E_a values thereafter steadily started with increasing methyl urea concentration to 7.5×10^{-2} mM. Thus, the presence of methyl urea in the acid medium probably alters the energy barrier for the metal corrosion through enhancing the apparent energy of activation resulting in the consequent decrease of the surface tendency for corrosion.

Table (5) shows the energy of activation E_a for the corrosion process and the pre-exponential factor A.

A linear relationship was found to exist between the experimental values of log A and the corresponding values of E_a in Figure (7), which could be expressed as [15]:

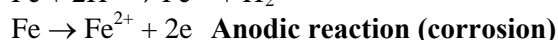
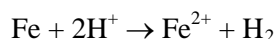
$$\text{Log A} = (I + m E_a) \dots\dots\dots(9)$$

where m and I are respectively the slope and the intercept of the plots in Fig.(7). Such a relationship is termed a (compensation effect) which is frequently found to describe the kinetics of catalytic reactions on alloys [16].

Equation (9) shows that simultaneous increase or decreases in E_a and log A for a particular system tend to compensate from the standpoint of the reaction rate.

Discussion

The most common and important electrochemical reactions in the corrosion of iron in the acidic solution is described by the following equations:



Many organic inhibitors work by an adsorption mechanism. The resultant film of chemisorbed inhibitor is then responsible for protection either by physically blocking the surface from the corrosion environment or by retarding the electrochemical processes. The main functional groups capable of forming chemisorbed bonds with metal surfaces are amino [17] (-NH₂), carboxyl (-COOH), and phosphonate (-PO₃H₂) although other functional groups or atoms can form co-ordinate bonds with metal surfaces. The protective properties of such compounds depend on the electron densities around the adsorption center. The higher electron density at the center, the more effective the inhibitor. The corrosion rate values (at low temperatures) in the presence of 1mm of methyl urea in acidic medium cause to increase the active sites on the metal surface by reducing the activation energy of rate determining step (rds) of the anodic or cathodic corrosion reaction.

The reduction in the dissolution of metal in the presence of methyl urea may be attributed to nitrogen and oxygen atoms present in the functional group. These groups are electroactive

Table (1): Corrosion rate (g/min) at different temperatures using different methyl urea concentration

T °C	T K	1/T ×10 ⁻³	Con. mm	Δwt _{loss}	Rate _{loss} mg.cm ⁻² . hour ⁻¹	-log Rate	Δwt Atomic	Rate Atomic mg.cm ⁻² . hour ⁻¹	-log Rate
12	285	3.5	0	0.096	0.00355	2.4498	0.1200	0.00446	2.35066
18	291	3.44	0	0.0057	0.00285	2.5452	0.0064	0.0032	2.4949
34	307	3.26	0	0.0233	0.01165	1.9337	0.03	0.015	1.8239
40	313	3.19	0	0.0424	0.01185	1.9263	0.044	0.022	1.6576
12	285	3.5	0.05	0.0569	0.00211	2.664	0.07944	0.00294	2.5317
18	291	3.44	0.05	0.0044	0.0022	2.658	0.00512	0.002559	2.5919
34	307	3.26	0.05	0.0184	0.0092	2.0362	0.02457	0.01228	1.9108
40	313	3.19	0.05	0.02372	0.01185	1.9263	0.029775	0.014887	1.8272
12	285	3.5	0.025	0.003	0.002	2.6989	0.07225	0.00268	2.5719
18	291	3.44	0.025	0.3078	0.00205	2.6882	0.00237	0.00474	2.3242
34	307	3.26	0.025	0.00455	0.00393	2.4056	0.024885	0.01244	1.9052
40	313	3.19	0.025	0.0152	0.01013	1.9944	0.02366	0.01183	1.92702
12	285	3.5	0.01	0.04706	0.001743	2.759	0.06021	0.00223	2.6517
18	291	3.44	0.01	0.00257	0.0012825	2.8919	0.00327	0.00163	2.7878
34	307	3.26	0.01	0.01631	0.008155	2.08857	0.0231	0.01155	1.9374
40	313	3.19	0.01	0.012	0.00655	2.1837	0.01578	0.00789	2.1029
12	285	3.5	0.0075	0.002	0.0013	2.886	0.0494	0.00183	2.7375
18	291	3.44	0.0075	0.00315	0.00175	2.75696	0.002514	0.00126	2.6300
34	307	3.26	0.0075	0.0111	0.007655	2.1161	0.0224	0.0112	1.9508
40	313	3.19	0.0075	0.0102	0.0068	2.16749	0.0180	0.009	2.0458
12	285	3.5	0.005	0.04984	0.001824	2.73904	0.0646	0.00239	2.6216
18	291	3.44	0.005	0.00281	0.001405	2.8523	0.00325	0.00163	2.7878
34	307	3.26	0.005	0.01724	0.008621	2.0644	0.0246	0.0122	1.9136
40	313	3.19	0.005	0.0131	0.00655	2.18376	0.02292	0.01146	1.9408
12	285	3.5	0.001	0.0714	0.00264	2.57859	0.0937	0.00347	2.4590
18	291	3.44	0.001	0.0033	0.00165	2.78252	0.003964	0.00198	2.7033
34	307	3.26	0.001	0.0217	0.00868	2.06148	0.0274	0.0137	1.8633
40	313	3.19	0.001	0.0249	0.01245	1.9048	0.01835	0.009178	2.0373

**Table (2): Protection efficiency, the degree of coverage
at different temperature**

Con. mm	T/K	1/T $\times 10^{-3}$	wt _{loss}	θ	P%	wt Atomic	θ	P%
0	285	3.5	0.096	-	-	0.1200	-	-
0	291	3.44	0.0057	-	-	0.0064	-	-
0	307	3.26	0.0233	-	-	0.03	-	-
0	313	3.19	0.0424	-	-	0.044	-	-
50	285	3.5	0.0569	0.4056	40.56	0.07944	0.3686	36.86
50	291	3.44	0.0044	0.22807	22.807	0.00512	0.2001	20.01
50	307	3.26	0.0184	0.213	21.3	0.02457	0.1811	18.11
50	313	3.19	0.02372	0.4472	44.72	0.029775	0.3233	32.33
25	285	3.5	0.003	0.4366	43.66	0.07225	0.4001	40.01
25	291	3.44	0.3078	0.280	28	0.00237	0.2591	25.91
25	307	3.26	0.00455	0.1663	16.33	0.024885	0.1705	17.05
25	313	3.19	0.0152	0.5222	52.22	0.02366	0.4622	46.22
10	285	3.5	0.04706	0.509	50.9	0.06021	0.5033	50.33
10	291	3.44	0.00257	0.55	55	0.00327	0.4890	48.90
10	307	3.26	0.01631	0.30	30	0.0231	0.230	23.00
10	313	3.19	0.012	0.7169	71.698	0.01578	0.6413	64.13
7.5	285	3.5	0.002	0.6338	63.38	0.0494	0.5902	59.12
7.5	291	3.44	0.00315	0.6638	66.38	0.002514	0.6071	60.71
7.5	307	3.26	0.0111	0.3429	34.29	0.0224	0.2540	25.40
7.5	313	3.19	0.0102	0.6792	67.92	0.0180	0.5909	59.09
5	285	3.5	0.04984	0.48	48.0	0.0646	0.4631	46.31
5	291	3.44	0.00281	0.507	50.7	0.00325	0.4920	49.20
5	307	3.26	0.01724	0.260	26.0	0.0246	0.1850	18.50
5	313	3.19	0.0131	0.691	69.10	0.02292	0.4791	47.91
1	285	3.5	0.0714	0.2563	25.634	0.0937	0.222	22.20
1	291	3.44	0.0033	0.4211	42.11	0.003964	0.3806	38.06
1	307	3.26	0.0217	0.686	68.60	0.0274	0.0851	85.10
1	313	3.19	0.0249	0.4127	41.27	0.01835	0.5828	58.28

Table (3): Maximum adsorption at different temperature

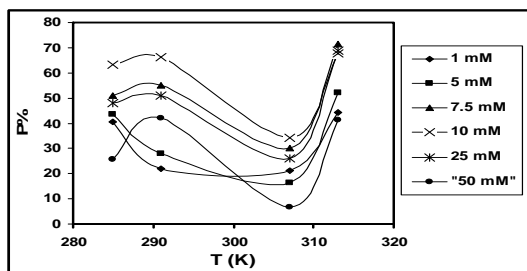
1/T $\times 10^{-3}$	$b \times 10^3$		Log b	
	loss	A.A	loss	A.A
3.5	0.3937	0.3968	2.595	2.590
3.44	0.6329	0.4545	2.8	2.658
3.26	0.100	0.500	3	2.699
31.9	0.9643	0.5181	2.98	2.714

Table (4): Thermodynamic parameter ΔG_a , ΔS_a and ΔH_a of the adsorption of methyl urea on carbon steel at different temperature

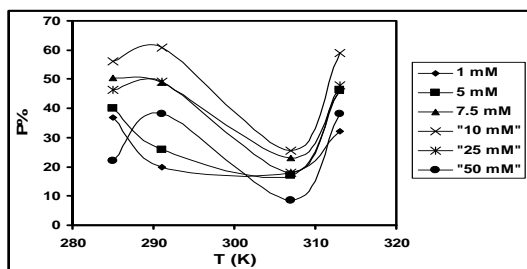
T (K)	$-\Delta G_a \text{ kJ.mol}^{-1}.\text{K}^{-1}$		$\Delta S_a \text{ J.mol}^{-1}.\text{K}^{-1}$		$\Delta H_a \text{ kJ.mol}^{-1}.\text{K}^{-1}$	
	loss	A.A	loss	A.A	loss	A.A
285	15.031	13.75	134.00	92.073	23.159	12.472
291	15.835	14.30	134.00	92.073	23.159	12.472
307	17.979	15.77	134.00	92.073	23.159	12.472
313	18.783	16.324	134.00	92.073	23.159	12.472

Table (5): The energy of activation E_a for the corrosion process and the per-exponential factor A

C Mm	$E_a \text{ (kJ)}$		Log A		I		M	
	Loss	A.A	loss	A.A	loss	A.A	loss	A.A
0	52.489	50.105	7.026	6.652	-3.024	-1.7029	0.1901	0.16304
50	50.893	48.929	6.577	6.321	-3.024	-1.7029	0.1901	0.16304
25	38.42	40.694	4.77	4.934	-3.024	-1.7029	0.1901	0.16304
10	41.327	47.752	3.839	5.98	-3.024	-1.7029	0.1901	0.16304
7.5	41.644	56.919	5.206	7.545	-3.024	-1.7029	0.1901	0.16304
5	35.914	54.782	4.2999	7.72	-3.024	-1.7029	0.1901	0.16304
1	42.954	42.427	4.584	5.155	-3.024	-1.7029	0.1901	0.16304

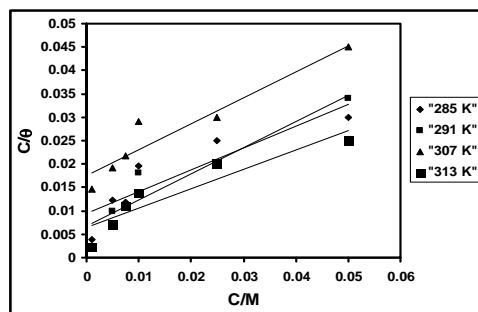


(a)

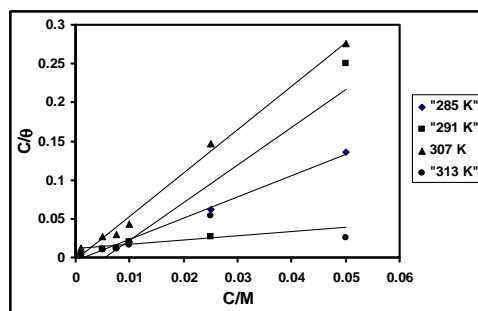


(b)

Figure(1): : The relationship between P% and T(K) with different methyl urea concentration
(a) by using weight loss measurement.
(b) by using atomic absorption measurement.

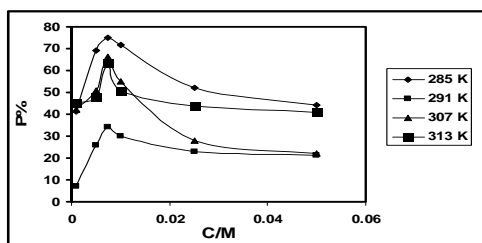


(a)

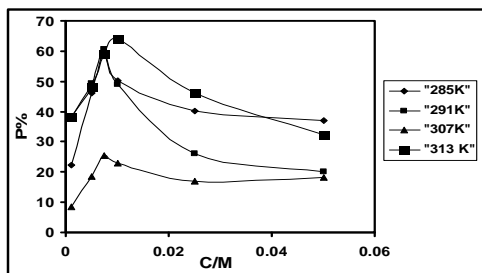


(b)

Figure(3): Langmuir adsorption of methyl urea on carbon steel in 1M HCl plotted (C/θ) versus methyl urea concentration.
(a) by using weight loss measurement.
(b) by using atomic absorption measurement.

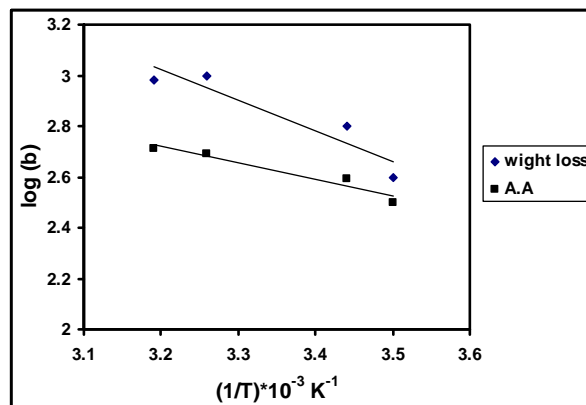


(a)

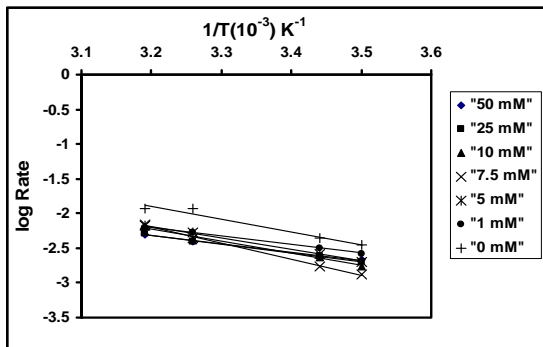


(b)

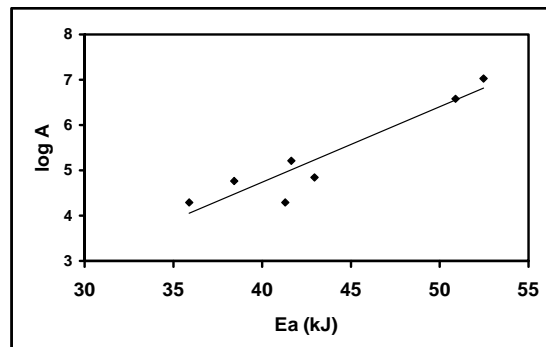
Figure (2): P% against methyl urea concentration at temperature ranges (285-313)K.
(a) by using weight loss measurement.
(b) by using atomic absorption measurement.



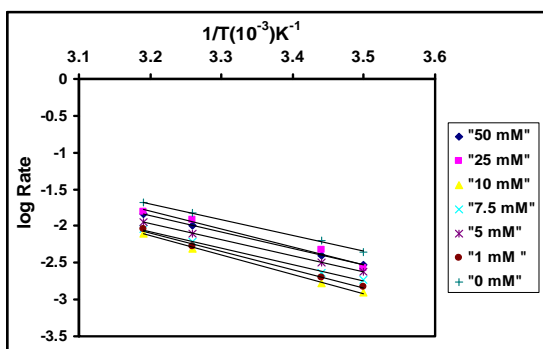
Figure(4): Log b revsus (1/T)
(a) by using wight loss measurement.
(b) by using atomic absorption measurement.



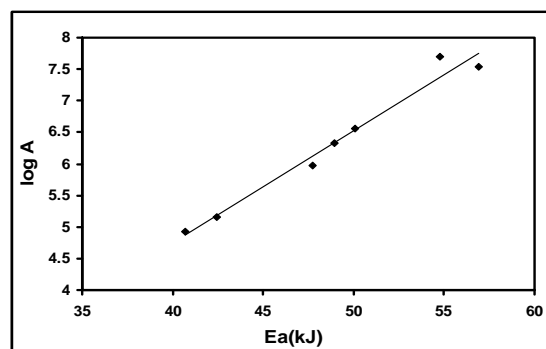
(a)



(a)



(b)



(b)

Figure (5): Arrhenius plot for the corrosion of carbon steel in 1M HCl at versus concentration.

- (a) by using weight loss measurement.
- (b) by using atomic absorption measurement.

Figure (7): E_a values plotted versus log A for the corrosion of carbon steel in 1M HCl with different urea concentration.

- (a) by using weight loss measurement.
- (b) by using atomic absorption measurement.

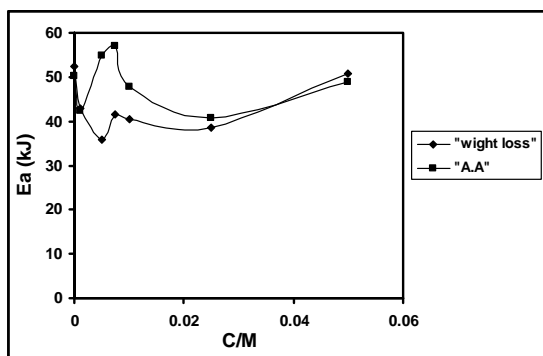


Figure.6: Values of apparent energy of activation (E_a) for the corrosion of carbon steel in 1M HCl solution as a function of methyl urea concentration (C/M)

and interact with the metals surface to a greater extent. Adsorption can be electrostatic or chemisorptive or the inhibitor can act simply by physically blocking the active sites.

The values of thermodynamic parameters for the adsorption of inhibitors can provide valuable information about the mechanism of corrosion inhibition. The endothermic adsorption process ($\Delta H_a > 0$) is attributed unequivocally to chemisorption [18], while generally, an exothermic adsorption process ($\Delta H_a < 0$) may involve either physisorption or chemisorption or a mixture of both the processes. In the present case, the positive sign of ΔH_a indicates that the adsorption of inhibitor molecules is an endothermic process[18]. The positive values of ΔS_a indicate that the adsorption is a process accompanied by an increase in entropy. Therefore, the values of ΔH and ΔS_a obtained by both are in good agreement. The values of ΔG_a are negative indicating that natural substance is strongly adsorbed at the metal surface[18]. A linear relationship between (C/θ) and C suggests that the inhibitor undergoes adsorption according to the langmuir adsorption isotherm. The temperature effect was significant in the presence of high concentration of methyl urea, and the P% increased with temperature increase generally. This results may be related to the modification of metal dissolution mechanism interpreted by many authors[16]. Temperature is a predominant factor in the formation of a protective layer at the metallic surface formed by metal inhibitor interaction, based on this reason.

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Table (1): Corrosion rate (g/min) at different temperatures using different methyl urea concentration

T °C	T K	1/T ×10 ⁻³	Con. mm	Δwt _{loss}	Rate _{loss} mg.cm ⁻² . hour ⁻¹	-log Rate	Δwt Atomic	Rate Atomic mg.cm ⁻² . hour ⁻¹	-log Rate
12	285	3.5	0	0.096	0.00355	2.4498	0.1200	0.00446	2.35066
18	291	3.44	0	0.0057	0.00285	2.5452	0.0064	0.0032	2.4949
34	307	3.26	0	0.0233	0.01165	1.9337	0.03	0.015	1.8239
40	313	3.19	0	0.0424	0.01185	1.9263	0.044	0.022	1.6576
12	285	3.5	0.05	0.0569	0.00211	2.664	0.07944	0.00294	2.5317
18	291	3.44	0.05	0.0044	0.0022	2.658	0.00512	0.002559	2.5919
34	307	3.26	0.05	0.0184	0.0092	2.0362	0.02457	0.01228	1.9108
40	313	3.19	0.05	0.02372	0.01185	1.9263	0.029775	0.014887	1.8272
12	285	3.5	0.025	0.003	0.002	2.6989	0.07225	0.00268	2.5719
18	291	3.44	0.025	0.3078	0.00205	2.6882	0.00237	0.00474	2.3242
34	307	3.26	0.025	0.00455	0.00393	2.4056	0.024885	0.01244	1.9052
40	313	3.19	0.025	0.0152	0.01013	1.9944	0.02366	0.01183	1.92702
12	285	3.5	0.01	0.04706	0.001743	2.759	0.06021	0.00223	2.6517
18	291	3.44	0.01	0.00257	0.0012825	2.8919	0.00327	0.00163	2.7878
34	307	3.26	0.01	0.01631	0.008155	2.08857	0.0231	0.01155	1.9374
40	313	3.19	0.01	0.012	0.00655	2.1837	0.01578	0.00789	2.1029
12	285	3.5	0.0075	0.002	0.0013	2.886	0.0494	0.00183	2.7375
18	291	3.44	0.0075	0.00315	0.00175	2.75696	0.002514	0.00126	2.6300
34	307	3.26	0.0075	0.0111	0.007655	2.1161	0.0224	0.0112	1.9508
40	313	3.19	0.0075	0.0102	0.0068	2.16749	0.0180	0.009	2.0458
12	285	3.5	0.005	0.04984	0.001824	2.73904	0.0646	0.00239	2.6216
18	291	3.44	0.005	0.00281	0.001405	2.8523	0.00325	0.00163	2.7878
34	307	3.26	0.005	0.01724	0.008621	2.0644	0.0246	0.0122	1.9136
40	313	3.19	0.005	0.0131	0.00655	2.18376	0.02292	0.01146	1.9408
12	285	3.5	0.001	0.0714	0.00264	2.57859	0.0937	0.00347	2.4590
18	291	3.44	0.001	0.0033	0.00165	2.78252	0.003964	0.00198	2.7033
34	307	3.26	0.001	0.0217	0.00868	2.06148	0.0274	0.0137	1.8633
40	313	3.19	0.001	0.0249	0.01245	1.9048	0.01835	0.009178	2.0373

