

Research Article

Inhibition of Mild Steel Corrosion by 3-Benzoylmethyl Benzimidazolium Hexafluoroantimonate in Acidic Solution

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The corrosion inhibition of mild steel in 1 M HCl solution by a synthesized compound (3-benzoylmethyl benzimidazolium hexafluoroantimonate) was investigated electrochemically and by weight loss experiments. The concentration of this inhibitor ranged from 5×10^{-7} M to 5×10^{-4} M. The effect of temperature (from 303 to 343 K) and concentrations (from 5×10^{-7} M to 5×10^{-4} M) were investigated. The percentage inhibition increased with the increase of the concentration of the inhibitor and reached about 98% at the concentration of 5×10^{-4} M at 303 K. The percentage inhibition decreased with the increase of temperature. The thermodynamic parameters for the adsorption of this inhibitor on the metal surface were calculated. This compound was found to be a very good corrosion inhibitor due to the presence of nitrogen in benzimidazole and phenyl ring.

1. Introduction

The corrosion of metals is a serious problem in many industries, installations, and civil services such as water and sewage supplies. One of the most useful and practical methods that used to control and protect metals against corrosion is the use of inhibitors, especially in acidic media. Not only the costs due to corrosion increase rapidly, but also the efficiency of the plants and the quality of the products are also reduced.

Most inhibitors are organic compounds containing polar groups strongly adsorbed on the metal surface [1, 2]. These inhibitors, which include the organic N, P, S, and OH groups, are known to be similar to catalytic poisons, as they decrease the reaction rate at the metal/solution interface without, in general, being involved in the reaction considered. It is generally accepted that most organic inhibitors act via adsorption at the metal/solution interface. The mechanism by which an inhibitor decreases the corrosion current is achieved by interfering with some of the steps for the electrochemical process.

The corrosion inhibition of mild steel in aggressive acidic solutions has been widely investigated. In industries, hydrochloric acid solutions are often used in order to remove scale and salts from steel surfaces, and cleaning tanks and

pipelines. This treatment may be prerequisite for coating by electroplating, galvanizing, or painting techniques. The acid must be treated to prevent an extensive dissolution of the underlying metal. This treatment involves the addition of some organic inhibitors to the acid solution that adsorb at the metal/solution interface by displacing water molecules on the surface and forming a compact barrier film.

Nitrogen-containing compounds as metal corrosion inhibitors have been studied thoroughly by many authors. These compounds included benzimidazole and imidazole derivatives [3–13], bipyrazole [14], stilbazole [15], quaternary ammonium salts [16–23], polyaminobenzoquinone polymers [24], substituted aniline-N-salicylidenes [25], amides [26], heterocyclic compounds [27, 28], and cationic surfactants [29, 30]. Other authors worked on phosphorous-containing and sulfur-containing inhibitors [15, 31–39]. Other studies involved the effect of addition of some ions on the inhibition efficiency of some organic compounds. These ions included chromium [40], iodide [41–43], and chloride [10, 44]. Structural effect of organic compounds as corrosion inhibitors was also studied [8, 42, 43, 45–47]. In all these studies, the nitrogen, phosphorous, and sulfur atom(s) in the compounds as well as the unsaturated double bonds like phenyl rings showed to be able to adsorb very well on the

metal surface and form protective layer, which in turn increased the corrosion inhibition with the increase in the concentration of the inhibitor, in some cases reaching 99% inhibition [15, 18, 36, 37].

No studies have been reported on 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) (Scheme 1), in terms of studying both the electrochemical and the temperature effect on the corrosion inhibition of mild steel in 1.0 M HCl solution. Mild steel was chosen in our studies since high temperature aggressive acids are widely used in industries in connection to mild and low alloy steels.

The aim of this work is

- (i) to synthesize a high percentage yield of pure 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI);
- (ii) to study, using potentiodynamic and weight loss measurements, the effect of temperature on the corrosion inhibition of mild steel in 1.0 M HCl solution by BMBI and to calculate the thermodynamic parameters.

The output of this study is intended to be the building block or the nucleus for a new family or group of imidazole onium derivatives in all studies of corrosion inhibitors.

2. Experimental Details

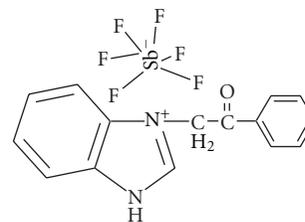
2.1. Synthesis of 3-Benzoylmethyl Benzimidazolium Hexafluoroantimonate (BMBI). The 3-benzoylmethyl benzimidazolium bromide salt (3) was prepared by refluxing an equimolar mixture of the 1-vinylimidazole and phenacyl bromide (2) in acetone as follows.

2.50 grams (0.021 mol) from benzimidazole (1) and 4.20 grams from phenacyl bromide (0.023 mol) (2), in 100 mL acetone, were refluxed for two hours. After cooling to room temperature, a crystalline solid of salt (3) was collected by filtration then washed with excess diethyl ether and dried.

The bromide salt (3) was converted to the hexafluoroantimonate salt (4) by treatment with potassium hexafluoroantimonate (K₂SbF₆) in methanol/water mixture 70/30% by volume. After stirring for 20 min, the reaction product was filtered, washed several times with water then with diethyl ether, and dried under vacuum at room temperature. Dissolution in chloroform and addition of excess diethyl ether gave the pure hexafluoroantimonate salt in 80 yield percent as shown in Scheme 2.

3. Electrochemistry

3.1. Electrode Preparation (Electrochemistry). A 5 mm diameter piece cut from a mild steel rod (IS 226 containing 0.18% C, 0.6% Mn, and 0.35% Si) supplied by "Reliable Steel Traders," Sharjah, UAE, formed the working electrode and was mounted, using Araldite epoxy resin, in a glass tube that fits in the electrochemical cell. Prior to each experiment, the working mild steel electrode was abraded using a series of carborundum papers starting with 600 grades and ending with 1200 grades. The electrode surface was then polished



SCHEME 1: 3-Benzoylmethyl benzimidazolium hexafluoroantimonate.

with 0.3 μm alumina on cloth, washed with deionized distilled water, and rinsed with pure ethanol before being transferred to the electrochemical cell that contained deaerated fresh electrolyte.

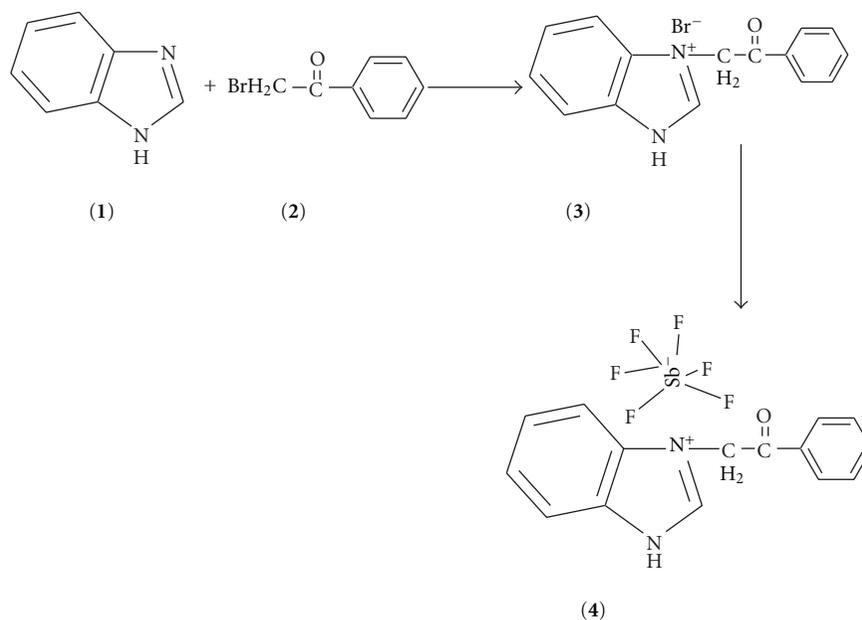
3.2. Instrumentation (Electrochemistry). The electrochemical cell (Figure 1) consisted of a mild steel working electrode (WE), a saturated calomel electrode (SCE) as a reference electrode (RE), and platinum gauze counter electrode (CE). Prior to each experiment, the electrolyte was deaerated by nitrogen bubbling. The cell was designed in a way that the nitrogen was allowed to escape into the solution, precluding its collection at the electrode surface.

In order to protect the working electrode from any substance that may be produced at the counter electrode during the electrochemical reactions, the counterelectrode compartment was separated from the working-electrode compartment with a glass frit. The following electrochemical instrument was used a PC controlled AUTO-LAB PGSTAT128N Modular Potentiostat (electrochemical workstation) (supplied from Metrohm) capable of driving currents up to ± 800 mA with an output potential across the cell of up to ± 10 V.

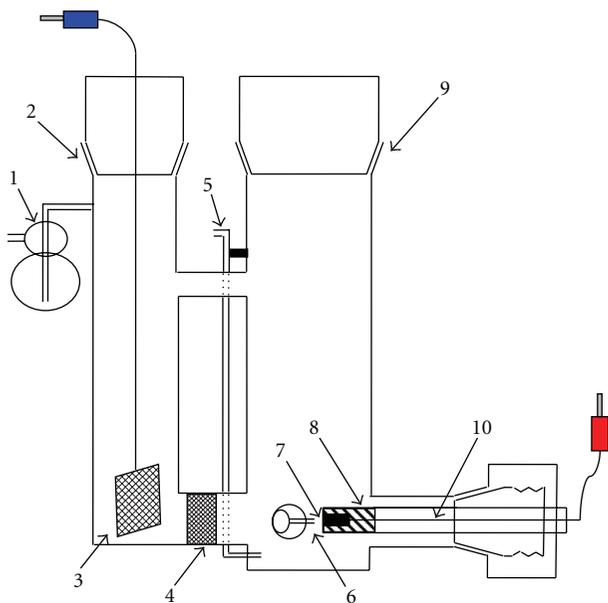
3.3. Measuring Procedure (Electrochemistry). Electrochemical corrosion measurements (Tafel plots) were carried out on the mild steel electrode, prepared as described before, in 1.0 M HCl and in 1.0 M HCl containing various concentrations of the prepared BMBI inhibitor. The concentration of the inhibitor ranged from 5×10^{-7} M to 5×10^{-4} M. Due to the restricted solubility of BMBI inhibitor, higher concentrations could not be prepared.

The electrode potential was scanned between over potentials of -100 mV to $+100$ mV versus SCE at a sweep rate of $1 \text{ mV} \cdot \text{s}^{-1}$.

3.4. Results and Discussions (Electrochemistry). Figure 2 shows the anodic and cathodic polarization curves (Tafel plot) of the mild steel electrode in deaerated 1.0 M HCl solution with and without the addition of various concentrations of 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI). The presence of the inhibitor affected both the anodic and cathodic branches of the curve as it can be clearly seen in Figure 2. The corrosion current was found to decrease with the increase of the concentration of BMBI inhibitor as shown in Table 1. In the absence of inhibitor (in



SCHEME 2: Synthesis of 3-benzoylmethyl benzimidazolium hexafluoroantimonate.



- (1) Gas bubbler
- (2) B 12 glass socket
- (3) Platinum gauze (counter electrode)
- (4) Glass frit
- (5) Inlet for nitrogen gas
- (6) luggin capillary (reference electrode)
- (7) Iron rod (working electrode)
- (8) Epoxy resin
- (9) B 24 glass socket
- (10) Copper wire

FIGURE 1: Electrochemical cell.

1.0 M HCl), the corrosion current was found to be 0.74 mA, which decreased sharply to 0.026 mA at 5×10^{-4} M of BMBI inhibitor in 1.0 M HCl (Table 1).

The percentage inhibition values of BMBI at various concentrations in 1.0 M HCl were calculated according to the following equation (1) and the results are shown in Table 1:

$$\text{Percentage Inhibition} = \frac{(I_{\text{Corr.}})_{\text{Uninh.}} - (I_{\text{Corr.}})_{\text{Inh.}}}{(I_{\text{Corr.}})_{\text{Uninh.}}} \times 100, \quad (1)$$

where $(I_{\text{Corr.}})_{\text{Uninh.}}$ is corrosion current in the uninhibited solution and $(I_{\text{Corr.}})_{\text{Inh.}}$ is corrosion current in inhibited solution.

Figure 3 shows the plot of the percentage inhibition versus the concentration of BMBI. In this figure, the percentage inhibition increases gradually from about 54% (with 5×10^{-7} M inhibitor) to reach about 96% with 5×10^{-4} M inhibitor.

4. Effect of Temperature

4.1. Specimen Preparation (Effect of Temperature). Rectangular specimens (1.0 cm \times 2.3 cm \times 0.3 cm) cut from large sheet of 3 mm thick mild steel (IS 226 containing 0.18% C, 0.6% Mn, and 0.35% Si) supplied by "Reliable Steel Traders," Sharjah, UAE, were used for weight loss measurements. A 2 mm diameter hole was drilled close to the upper edge of the specimen and served to be hooked with a glass rod for immersion purposes. Prior to each experiment, the specimens were polished with 600 grade emery paper, rinsed with distilled water, degreased with acetone, dried, and finally weighed precisely on an accurate analytical balance.

TABLE 1: Tafel corrosion currents and percent inhibitions of 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) at various concentrations in 1.0 M HCl at room temperature.

	1.0 M HCl	1.0 M HCl + 5×10^{-7} M BMBI	1.0 M HCl + 5×10^{-6} M BMBI	1.0 M HCl + 5×10^{-5} M BMBI	1.0 M HCl + 5×10^{-4} M BMBI
E_{rest}/V versus SCE	-0.459	-0.472	-0.472	-0.461	-0.583
$I_{corrosion}/mA$	0.74	0.34	0.27	0.16	0.026
Percent Inhibition	—	54.05	63.51	78.38	96.49

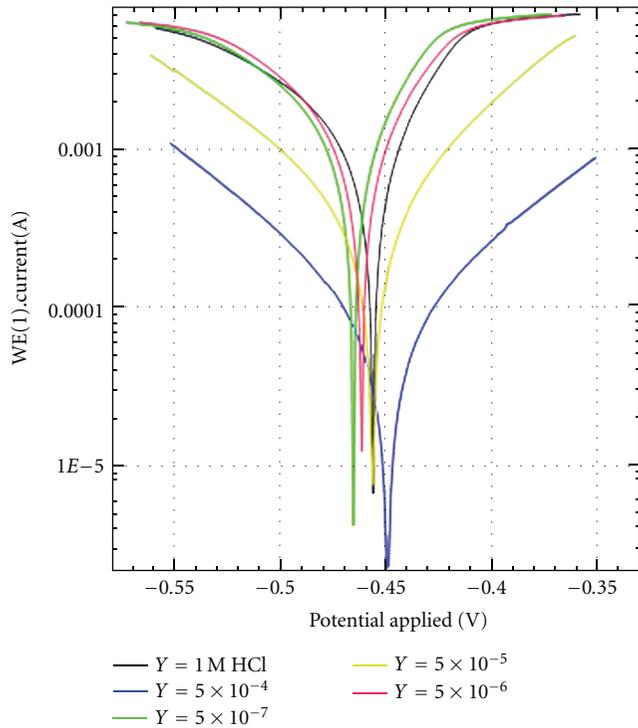


FIGURE 2: Anodic and cathodic polarization curves of mild steel in an uninhibited 1.0 M HCl solution and in 1.0 M HCl containing various concentrations of 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) at ambient temperature. (1) 1.0 M HCl; (2) 1.0 M HCl + 5.0×10^{-7} M inhibitor; (3) 1.0 M HCl + 5.0×10^{-6} M inhibitor; (4) 1.0 M HCl + 5.0×10^{-5} M inhibitor; (5) 1.0 M HCl + 5.0×10^{-4} M inhibitor.

4.2. *Instrumentation (Effect of Temperature)*. The experimental setup consisted of a 250 mL round bottom flask fitted with a reflux condenser and a long glass rod on which the specimen was hooked and in turn immersed in a thermally controlled water bath.

4.3. *Measuring Procedure (Effect of Temperature)*. The flask was filled with 100 mL of 1.0 M HCl solution either with or without BMBI of various concentrations, then placed in water bath. As soon as the required working temperature was reached, the precisely weighed mild steel specimen was immersed in the solution and left there for exactly six hours, after which the sample was removed, rinsed with distilled deionized water, degreased with acetone, dried, and finally weighed precisely on an accurate analytical balance. This

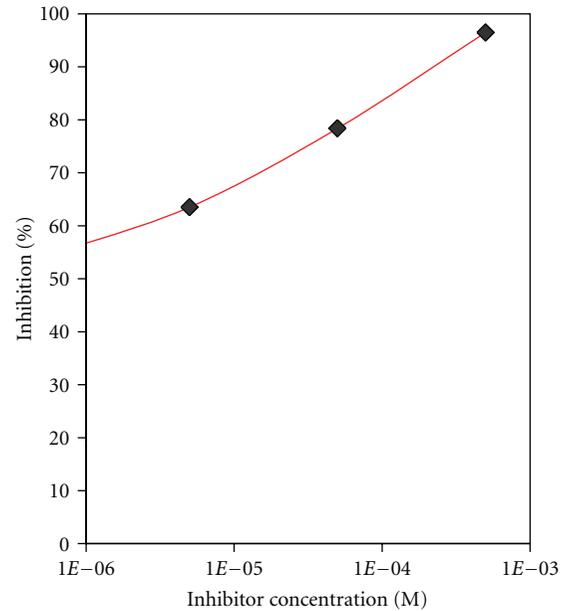


FIGURE 3: Percentage inhibition versus the concentration of 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) at ambient temperature.

procedure was repeated with all the samples with a variety of inhibitor concentrations ranging from 5×10^{-7} M up to 5×10^{-4} M and at temperatures ranging from 303 K to 343 K.

4.4. *Results and Discussions (Effect of Temperature)*. Weight loss corrosion tests were carried out on the mild steel in 1 M HCl in the absence and presence of (BMBI) over a period of 6 hours. Table 2 represents the corrosion rates [$mg \cdot cm^{-2} \cdot h^{-1}$], and the percentage efficiencies [%] for the studied inhibitor with concentrations varying from 5×10^{-7} M to 5×10^{-4} M at 303, 313, 323, 333, and 343 K, respectively. The percentage efficiency was calculated according to the following expression (2):

$$\% \text{ Inhibition} = \frac{W_{Uninh.} - W_{Inh.}}{W_{Uninh.}} \times 100, \quad (2)$$

where $W_{Uninh.}$ is corrosion rate without inhibitor; and $W_{Inh.}$ is corrosion rate with inhibitor.

Figures 4 and 5 show the plots of the corrosion rate of (BMBI) as a function of concentration at 303, 313, 323, 333, and 343 K extracted from Table 2. At 303 K (Table 2, Figure 4), the corrosion rate dropped sharply from the value $0.961 mg \cdot cm^{-2} \cdot h^{-1}$ (1 M HCl in the absence of the

TABLE 2: Effect of concentration of 3-Benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) on the corrosion rate ($\text{mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$) and percentage efficiency of mild steel in 1.0 M HCl at various temperatures.

Concentration of Inhibitor	Temperature/K									
	303		313		323		333		343	
	Corr. Rate	% Efficiency	Corr. Rate	% Efficiency	Corr. Rate	% Efficiency	Corr. Rate	% Efficiency	Corr. Rate	% Efficiency
1 M HCl	0.961	—	1.394	—	4.671	—	12.225	—	26.280	—
1 M HCl + 5×10^{-7} M	0.363	62.3	0.686	50.8	2.673	42.8	8.539	30.2	21.874	16.8
1 M HCl + 5×10^{-6} M	0.229	76.2	0.508	63.6	2.177	53.4	6.619	45.9	17.227	34.4
1 M HCl + 5×10^{-5} M	0.102	89.4	0.182	86.9	1.179	74.8	4.440	63.7	11.835	55.0
1 M HCl + 5×10^{-4} M	0.018	98.1	0.052	96.0	0.256	94.5	2.321	81.0	7.503	71.5

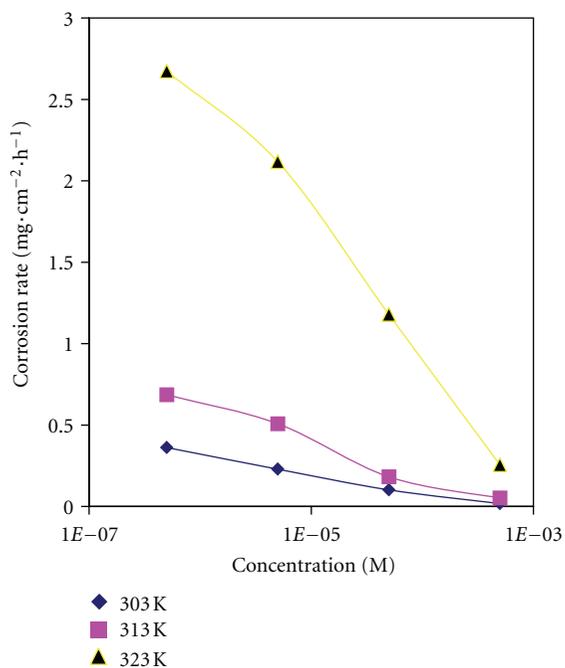


FIGURE 4: Effect of concentration of 3-Benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) on the corrosion rate ($\text{mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$) of mild steel in 1.0 M HCl at various temperatures.

inhibitor) to the value $0.363 \text{ mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ (62.3% inhibition) when 5×10^{-7} M of (BMBI) was present in the 1 M HCl. This corrosion rate continued to decrease gradually and linearly to reach $0.018 \text{ mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ (98.1% inhibition) at 5×10^{-4} M. At 313 K (Table 2, Figure 4); the curve showed to have similar shape as that obtained at 303 K. The corrosion rate decreased gradually and linearly from $0.686 \text{ mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ (50.8% inhibition) when 5×10^{-7} M of (BMBI) to reach about $0.052 \text{ mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ (96.0%) at 5×10^{-4} M.

At 323 K (Table 2, Figure 4), the corrosion rate decreased also linearly but more steeply from $2.673 \text{ mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ (42.8% inhibition) when 5×10^{-7} M of (BMBI) to reach about $0.256 \text{ mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ (94.5%) at 5×10^{-4} M.

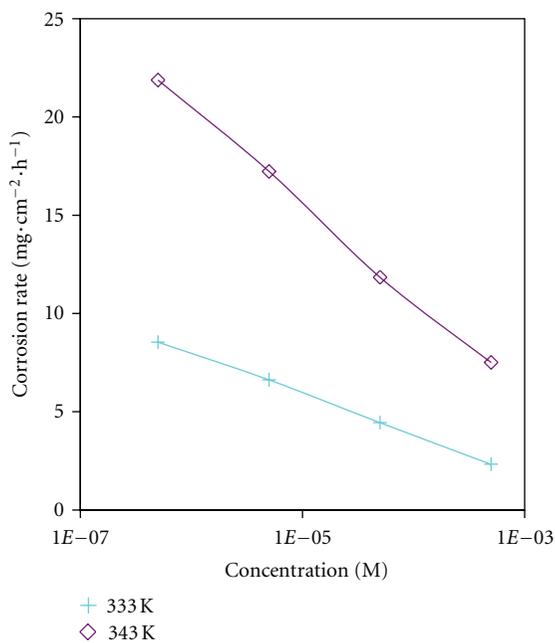


FIGURE 5: Effect of concentration of 3-Benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) on the corrosion rate ($\text{mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$) of mild steel in 1.0 M HCl at various temperatures.

In Figure 5, the same behavior is shown as in Figure 4. The corrosion rate at 333 and 343 K are shown as a function of the concentration of (BMBI). It can be clearly seen that the presence of the (BMBI) inhibitor at these high temperatures has acted as a corrosion inhibitor reaching a percent inhibition of 81.0% and 71.5% when 5×10^{-4} M inhibitor was employed at 333 K and 343 K, respectively.

Figure 6 shows the plots of the % inhibition versus the concentration of the inhibitor at temperatures of 303, 313, 323, 333, and 343 K, respectively. This figure showed that the % inhibition increased as the temperature decreased at the same inhibitor concentration. The presence of the inhibitor has greatly increased the % inhibition at all temperatures.

TABLE 3: The data obtained from the weight loss measurements for Arrhenius equation: ($1/T$) against \ln (corrosion rate).

$(1/T) \times 10^3 \text{ K}^{-1}$	Ln corrosion rate ($\text{mg} \cdot \text{cm}^{-2} \cdot \text{h}^{-1}$)				
	1 M HCl	1 M HCl + 5×10^{-7} M	1 M HCl + 5×10^{-6} M	1 M HCl + 5×10^{-5} M	1 M HCl + 5×10^{-4} M
3.30	-0.03978	-1.01611	-1.47403	-2.28278	-4.01738
3.19	0.332177	-0.37688	-0.67727	-1.70375	-2.96423
3.10	1.541373	0.9832	0.77795	0.16467	-1.36258
3.00	2.503483	2.14464	1.88994	1.49065	0.842
2.92	3.268808	3.0853	2.84648	2.47106	2.0153

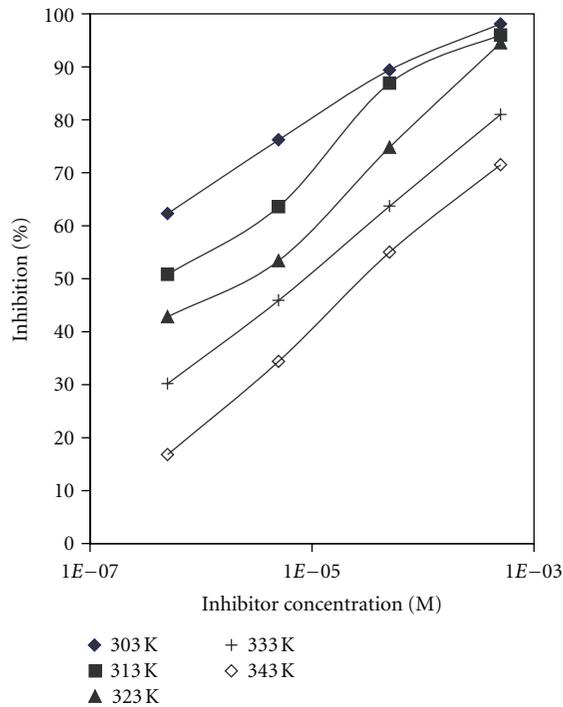


FIGURE 6: Effect of concentration of 3-Benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) triphenyl phosphonium bromide on the percent inhibition of mild steel in 1.0 M HCl at various temperatures.

TABLE 4: The activation energy (E_a) for the corrosion of mild steel in 1.0 M HCl with and without 3-benzoylmethyl benzimidazolium hexafluoroantimonate inhibitor at various concentrations.

System	Activation energy, E_a ($\text{kcal} \cdot \text{mol}^{-1}$)			
	5×10^{-4} M	5×10^{-5} M	5×10^{-6} M	5×10^{-7} M
1 M HCl	18.27	18.27	18.27	18.27
1 M HCl + BMBI	33.06	26.43	23.35	22.31

The data obtained from the weight loss measurements (Table 3) were plotted in accordance to Arrhenius equation (3):

$$\ln \text{rate} = -\frac{E_a}{RT} + \text{const.}, \quad (3)$$

where E_a is activation energy [$\text{kcal} \cdot \text{mol}^{-1}$], R is gas constant [$\text{kcal} \cdot \text{mol}^{-1}$], T is absolute temperature [K], and const. is constant.

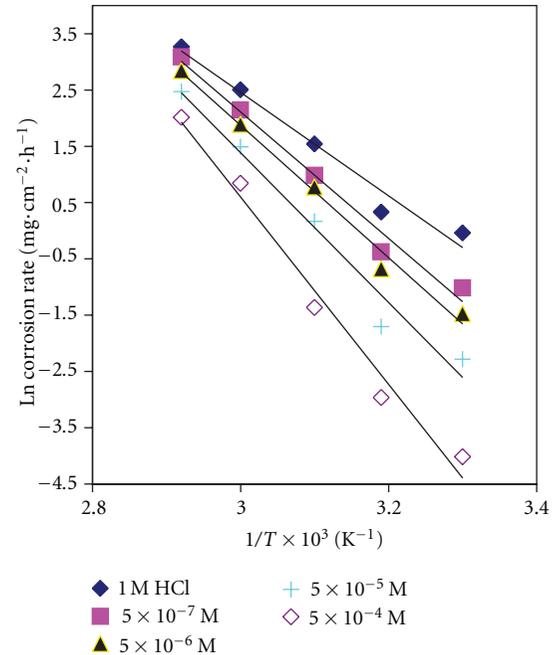


FIGURE 7: Effect of temperature on the corrosion rate of mild steel in 1.0 M HCl solution with and without the presence of various concentrations of 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI).

Figure 7 represents the Arrhenius plot of the corrosion of mild steel in 1 M HCl solution (\ln corrosion rate as a function of $1/T$) with and without the presence of (BMBI) at concentrations ranging from 5×10^{-4} M to 5×10^{-7} M. From this figure, the slope ($-E_a/R$) of each individual line was determined and used to calculate the activation energy according to (3) and taking $R = 1.987 \times 10^{-3} \text{ kcal} \cdot \text{mol}^{-1}$ (Table 4). The increase of concentration of (BMBI) (from 5×10^{-7} M to 5×10^{-4} M) increased the activation energies for the corrosion of mild steel in 1 M HCl (initially $18.27 \text{ kcal} \cdot \text{mol}^{-1}$) (Table 4). The increase in the activation energies for the corrosion is attributed to a decrease in the adsorption of the inhibitor on the metal surface as the temperature increased; subsequently, an increase in the corrosion rate will result due to the greater exposed area of the metal surface to the acid.

The results in Table 4 show that the activation energy (E_a) for the corrosion of mild steel in the presence of the inhibitor is higher compared to the activation energy in the absence of

TABLE 5: Effect of concentration of 3-benzoylmethyl benzimidazolium hexafluoroantimonate on surface coverage for mild steel in 1.0 M HCl at various temperatures.

Concentration of inhibitor	Temperature/K				
	303	313	323	333	343
	Surface coverage θ				
1 M HCl + 5×10^{-7} M	0.623	0.508	0.428	0.302	0.168
1 M HCl + 5×10^{-6} M	0.762	0.636	0.534	0.459	0.344
1 M HCl + 5×10^{-5} M	0.894	0.869	0.748	0.637	0.550
1 M HCl + 5×10^{-4} M	0.981	0.960	0.945	0.810	0.715

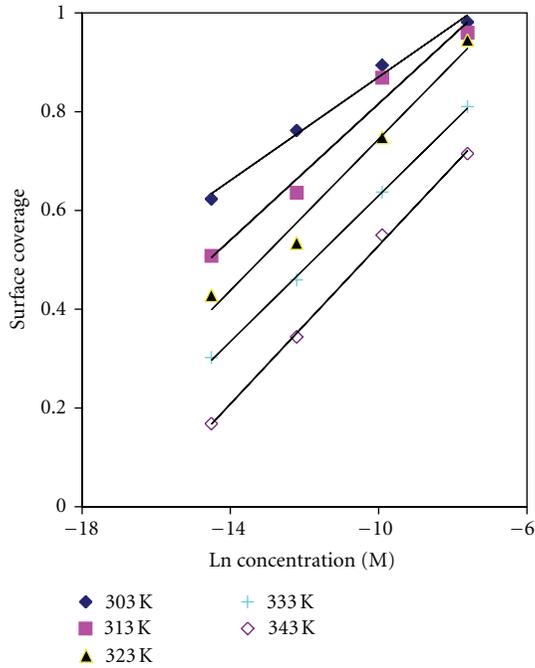


FIGURE 8: Effect of concentration of 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) on the surface coverage of mild steel in 1.0 M HCl at various temperatures.

inhibitor at all concentrations ranging from 5×10^{-4} M to 5×10^{-7} M (from about 33 to about 22 kcal·mol⁻¹, resp.). This can be attributed to the fact that higher values of E_a in the presence of inhibitor compared to its absence are generally consistent with a physisorption, while unchanged or lower values of E_a in inhibited solution suggest charge sharing or transfer from the organic inhibitor to the metal surface to form coordinate covalent bonds [42, 43].

Table 5 shows the surface coverage, θ , of various concentrations of (BMBI) (from 5×10^{-7} M to 5×10^{-4} M) on mild steel surface as a function of temperature. These values were extracted from the corresponding % efficiency values reported earlier in Table 2. The plot of surface coverage against the natural logarithm of the concentration, $\ln C$, for mild steel in the presence of the various inhibitor concentrations is shown in Figure 8. After examining the data and adjusting them to different theoretical adsorption isotherms,

it was concluded that all inhibitors were adsorbed on the mild steel surface according to Temkin isotherm:

$$-2a\theta = \ln KC, \quad (4)$$

where a is molecular interaction constant, θ is degree of coverage, K is equilibrium constant for the adsorption reaction, and C is concentration of the inhibitor.

The equilibrium constant for the adsorption reaction, K , is related to the standard free energy of adsorption via the following equation given by Damaskin et al. [1]:

$$K = \frac{1}{55.5} \exp\left(-\frac{\Delta G}{RT}\right), \quad (5)$$

where K is equilibrium constant for the adsorption reaction, 55.5 is concentration of water [mol·L⁻¹], ΔG is standard free energy [kcal·mol⁻¹], R is gas constant [kcal·mol⁻¹], and T is absolute temperature [K].

According to (4), the straight lines shown in Figure 8 will have the following slopes and intercepts:

$$\text{Slope} = -\frac{1}{2a}, \quad (6)$$

$$\text{Intercept} = -\frac{1}{2a} \ln K. \quad (7)$$

Combination of (6) and (7) leads to the following relationship:

$$\text{Intercept} = \text{Slope} \times (\ln K), \quad (8)$$

from which the equilibrium constant for the adsorption reaction, K , can be calculated:

$$K = e^{(\text{Intercept}/\text{slope})}. \quad (9)$$

The standard free energy of adsorption of the inhibitor, ΔG^0 , can be calculated from the results in Figure 8 used to calculate the equilibrium constant, K , and (5) at various temperatures (303 to 343 K).

The enthalpy of adsorption, ΔH^0 , for the inhibitor can be calculated from the following equation:

$$\Delta H^0 = E_a - RT. \quad (10)$$

The entropy, ΔS^0 , can be calculated at various temperatures for the inhibitor using the following equation:

$$\Delta G^0 = \Delta H^0 - T\Delta S^0. \quad (11)$$

TABLE 6: The free energy of adsorption (ΔG_{ads}) for mild steel in 1.0 M HCl in the presence of 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) at various temperatures (303 K–343 K).

$\Delta G, \text{kcal} \cdot \text{mol}^{-1}$				
303 K	313 K	323 K	333 K	343 K
-18.55	-16.07	-15.33	-15.06	-14.07

TABLE 7: The enthalpy of adsorption (ΔH) for mild steel in 1.0 M HCl in the presence of 2×10^{-5} M 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) inhibitor at various temperatures (303 K–343 K).

$\Delta H, \text{kcal} \cdot \text{mol}^{-1}$				
303 K	313 K	323 K	333 K	343 K
32.46	32.44	32.42	32.40	32.38

TABLE 8: The change in entropy (ΔS) for mild steel in 1.0 M HCl in the presence of 3-benzoylmethyl benzimidazolium hexafluoroantimonate (BMBI) inhibitor at various temperatures (303 K–343 K).

$\Delta S, \text{kcal} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$				
303 K	313 K	323 K	333 K	343 K
0.168	0.155	0.148	0.143	0.135

Tables 6, 7, and 8 show the thermodynamic data obtained in the presence of the inhibitor at 5×10^{-4} M. These thermodynamic quantities represent the algebraic sum of the values for adsorption and desorption. The negative value of ΔG^0 indicates the spontaneous adsorption of inhibitor on the surface of the mild steel. The standard free energy, ΔG^0 , increases from about $-19 \text{ kcal} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ at 303 K to about $-14 \text{ kcal} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ at 343 K. The adsorption process is believed to be exothermic and associated with a decrease in entropy (ΔS) of solute, while the opposite is true for the solvent. The gain in entropy which accompanies the substitutional adsorption process is attributed to the increase in the solvent entropy. This agrees with the general suggestion that the values of ΔG^0 increase with the increase of inhibition efficiency as the adsorption of organic compound is accompanied by desorption of water molecules off the surface [33, 45].

The high inhibition efficiency may be attributed to the preferred flat orientation of this compound on the metal surface. The interaction occurs between the delocalized π -electrons of the benzimidazole and phenyl rings, the carbonyl group (C=O), and the lone pair of electrons on N and O atoms with the positively charged metal surface.

5. Conclusion

3-Benzoylmethyl benzimidazolium hexafluoroantimonate was found to be a highly efficient inhibitor for mild steel in 1.0 M HCl solution, reaching about 98% at 5.0×10^{-4} M and room temperature, a concentration considered to be very moderate.

3-Benzoylmethyl benzimidazolium hexafluoroantimonate is a potential corrosion inhibitor since it contains not only nitrogen atom, but also phenyl and benzimidazole ring together with carbonyl group (C=O). It was apparent from the molecular structure that this compound would be adsorbed onto the metal surface through the lone pair of electron of nitrogen and oxygen and pi electrons of the aromatic rings (phenyl and benzimidazole) and the carbonyl group.

The percentage of inhibition in the presence of this inhibitor decreased as the temperature increased which indicates that physical adsorption was the predominant inhibition mechanism, because the quantity of adsorbed inhibitor decreases with increasing temperature.

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