

Corrosion Studies of Various Salt Solutions on Carbon Steel alloy

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ABSTRACT

Corrosion refers to a chemical (dry corrosion) or electrochemical (wet corrosion) reaction of a metal and the surrounding environment due to erosion of steel and its alloys or atmospheric gases causing substances used to break down or lose component atoms. Corrosion is also defined as an electrochemical process in which oxidation and reduction of metal occur simultaneously in the presence of an oxidizing agent such as oxygen. Carbon Steel and Mild Steel are the most common steels used in many industries as well as everyday life for the design and manufacture of a variety of applications. Carbon steel and low carbon will corrode severely when exposed to a corrosive medium. Scientists have always wanted to understand the corrosion process and ways to control it. A number of corrosion inhibitors have been reported to control the corrosion of steel and its alloys in different corrosion systems. Every step towards finding a new Corrosion Inhibitor for a corrosion remediation project will not only result in significant savings, but will also help engineers keep plants and machinery running smoothly as Corrosion occurs. Carbon Steel, Stainless Steel, and Mild Steel are the most common materials used in the design and manufacture of the Chloride ions can corrode steel, stainless steel, and mild steel and are found in plumbing, electrical equipment, boilers, condensing units, etc. can cause problems. The sea is also abundant in chloride, which is used for injection into water in oil for cooling, such as in desalination plants. Chemical corrosion inhibitors are generally used in manufacturing and processing. The challenge, however, is to develop a new corrosion inhibitor that will protect material and make it a good friend in many situations. Surfactants are environmentally acceptable as corrosion inhibitors and is very economical and readily available. The purpose of this article is to determine the ability of surfactants to prevent corrosion of on carbon, stainless and mild steel surfaces. The various uses and properties of various surfactants are also discussed. The effect of surfactant concentration, temperature and corrosion inhibition mechanisms, and type of adsorption are also discussed in this book. In this study, we try to study in detail surfactants as corrosion inhibitors to control corrosion of carbon steel, stainless steel and small iron in an acidic environment. Experiments were performed using both gravitational and electrochemical polarization methods, and the results of all studied surfactants used in this study are discussed in detail.

Keywords: Corrosion Inhibitor, Carbon Steel, Surfactant, Electrochemical Polarization, Acidic Environment.

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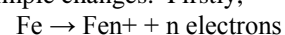
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I. INTRODUCTION

The corrosion especially due to salt formation. Corrosion is the deterioration of materials by chemical interaction with their environment. The term corrosion is sometimes also applied to the degradation of plastics, concrete and wood, but generally refers to metals. The most widely used metal is iron (usually as steel). For example ship propeller sinks into the sea water and in sea water, found the salt. Due to this salt formation in sea water, this affects the ship propeller. So, here totally describes the salt formation corrosion and other corrosion.

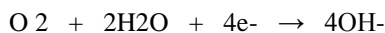
We have all seen corrosion and know that the process produces a new and less desirable material from the original metal and can result in a loss of function of the component or system. The corrosion product we see most commonly is the rust which forms on the surface of steel and somehow Steel → Rust

For this to happen the major component of steel, iron (Fe) at the surface of a component undergoes a number of simple changes. Firstly,



the iron atom can lose some electrons and become a positively charged ion. This allows it to bond to other groups of atoms that are negatively charged.

We know that wet steel rusts to give a variant of iron oxide so the other half of the reaction must involve water (H₂O) and oxygen (O₂) something like this

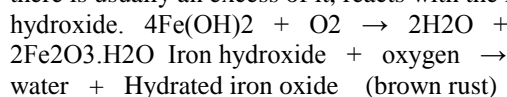


This makes sense as we have a negatively charged material that can combine with the iron and electrons, which are produced in the first reaction are used up. We can, for clarity, ignore the electrons and write



Iron Hydroxide

Oxygen dissolves quite readily in water and because there is usually an excess of it, reacts with the iron hydroxide.



This series of steps tells us a lot about the corrosion process. Ions are involved and need a medium to move in (usually water) (2) Oxygen is involved and needs to be supplied (3) The metal has to be willing to give up electrons to start the process (4) A new material is formed and this may react again or could be protective of the original metal (5) A series of simple steps are involved and a driving force is needed to achieve them. The most important fact is that interfering with the steps allows the corrosion reaction to be stopped or slowed to a manageable rate.

Uniform corrosion, as the name suggests, occurs over the majority of the surface of a metal at a steady and often predictable rate. Although it is unsightly its predictability facilitates easy control, the most basic method being to make the material thick enough to function for the lifetime of the component. Uniform corrosion can be slowed or stopped by using the five basic facts;

- (1) Slow down or stop the movement of electrons

- (a) Coat the surface with a non-conducting medium such as paint, lacquer or oil

- (b) Reduce the conductivity of the solution in contact with the metal an extreme case being to keep it dry. Wash away conductive pollutants regularly.

- (c) Apply a current to the material (see cathodic protection).

- (2) Slow down or stop oxygen from reaching the surface. Difficult to do completely but coatings can help.

- (3) Prevent the metal from giving up electrons by using a more corrosion resistant metal higher in the electrochemical series. Use a sacrificial coating which gives up its electrons more easily than the metal being protected. Apply cathodic protection. Use inhibitors.

- (4) Select a metal that forms an oxide that is protective and stops the reaction. Control and consideration of environmental and thermal factors is also essential.

II. Materials and Methods:

EXPERIMENTAL PROCEDURE

The stability and concentration of hydrochloric acid vary in industry. Therefore, it has different corrosive properties depending on the strength of hydrochloric acid. To overcome this problem, 1.0M concentration of hydrochloric acid was prepared. The experiments were carefully designed to evaluate the corrosion inhibiting effectiveness of surfactants as corrosion inhibitors.

We carefully monitored the consistency of the data by repeating the experiments and sometimes even making triplicate.

Materials

Carbon steel, mild steel and stainless steel used for investigations was in the form of sheet (0.25mm thick) and had the following compositions.

Table 1: Carbon steel, mild steel and stainless steel used for investigations was in the form of sheet (0.25mm thick) and had the following compositions.

Element	C	Si	Mn	S	P	Ni	Cu	Cr	Fe
Weight %age(w/w)									
Carbon Steel	0.54	0.05	0.32	0.05	0.20	0.03	0.01	0.01	Balance
Stainless Steel	1.8	0.08	0.58	0.07	0.51	0.05	0.03	0.04	Balance
Mild Steel	0.21	0.03	0.27	0.06	0.34	0.07	0.01	0.11	Balance

Sample Preparations

Weight Loss Measurements:

For the weight loss test, metal samples with a size of 3.0 x 1.5 cm² were cut from the metal sheet with a sharp edged metal cutter, while samples

with a size of 5.0 x 1.5 cm were taken for the electrochemical polarization experiment. After selecting several metal samples, they were mechanically polished with different emery papers of 150, 300 and 600 microns, respectively, and then thoroughly cleaned with triple distilled water and acetone. The sample was dried with a hot hair dryer and stored in a silica gel desiccator. The acid used is made from AR grade hydrochloric acid. Prepare 1.0 M hydrochloric acid using double distilled water. In acidic media, all organic surfactants are used as corrosion inhibitors in concentrations of 20 to 150 ppm. After recording the initial weight of the metal sample on the Japanese Mettler Toledo AB 135-FACT single pan analytical balance (accuracy 0.01 mg), place the metal sample at an angle into a 250 ml Glass borosilicate beaker of 200 ml each. Acidic solution as corrosion medium with or without inhibitor. Weight loss corrosion experiments and electrochemical polarization experiments were carried out at different temperatures, that is, in a controlled heat exchanger. 30, 40 and 50°C with an accuracy of ±0.1°C. The samples were removed from the beakers after 24 hours of exposure and rinsed under running water. The loosely adhering corrosion products are removed with the help of rubber stoppers and the sample is rinsed again with triple distilled water, dried with a hot hair dryer and weighed again. Calculate the corrosion rate in mils per year (mpy) and the inhibition efficiency as a percentage using the formula below.

$$\text{Corrosion rate (mpy)} = \frac{534 \times W}{DAT} \quad \dots(1)$$

Where

W = Weight loss (mg), D = Density of carbon steel (gm/cm^3), A = Area of specimen (sq. inch), T = Exposure time (hours). The extent of surface coverage (θ) by the organic surfactant molecule were calculated from the following equation:

$$\theta = \frac{\left[\frac{\Delta W_{in}}{\Delta W_{out}} \right]}{\left[1 + \frac{\Delta W_{in}}{\Delta W_{out}} \right]} \quad \dots(2)$$

Where, ΔW_{out} and ΔW_{in} are weight losses of metal per unit area in absence and presence of inhibitor at given time period and temperature, respectively.

Electrochemical polarization investigation were carried out in 500 ml glass cell specially designed for the purpose having three electrodes system assembly. Potentiostatic polarization of the working electrode was carried out by using a Potentiostat / Galvanostat PGS 201

T (Tacussel, France). The working electrode has an arrangement to hold the metal coupons under study, Platinum electrode/auxiliary electrode was used as counter electrode. Linear polarization resistance measurements were performed potentiostatically by scanning through a potential range of 14 mV above and below the OCP value in steps of 2 mV. Different electrochemical experiments were carried out in absence and presence of surfactant molecule at their different temperature at 30, 40 and 50°C. The resulting current is plotted against the potential and slope of the line is measured

The corrosion current, I_{corr} is related to the slope of the line by Stern-Geary equation.

$$\frac{\Delta E}{\Delta i} = \frac{\beta_a \times \beta_c}{2.303 I_{corr} (\beta_a + \beta_c)} \quad \dots(3)$$

Where $\frac{\Delta E}{\Delta i}$ is the slope which is linear polarization resistance (R_p), β_a and β_c are anodic and cathodic Tafel slopes respectively and I_{corr} is the corrosion current density in $\mu\text{A/cm}^2$.

The anodic and cathodic Tafel slopes were measured after recording anodic and cathodic polarization curves of the specimen up to a maximum shift of ± 140 mV from OCP value in step of 10 mV. Experiments were carried out in absence and presence of the inhibitor at their 20 to 150 ppm concentrations at 30, 40 and 50°C.

Rearranging the above equation:

$$I_{corr} = \frac{\beta_a \beta_c}{2.303 (\beta_a + \beta_c)} \times \frac{1}{R_p} \quad \dots(4)$$

The corrosion current density I_{corr} is related to the corrosion rate by the equation.

$$\text{Corrosion rate (C.R.) (mpy)} = \frac{0.1288 \times I_{corr} \times Eq. Wt.}{D} \quad \dots(5)$$

$$S_6 = \frac{1 - \theta_{1+2}}{1 - \theta_{1+2}} \quad \dots(6)$$

The interaction of inhibitor molecules can be described by introducing of an parameter, S_6 , obtained from the surface coverage values (θ) of the anion, cation and both. Aramiki and Hackerman calculated the synergism parameter, S_6 , using the following equation.

Where $\theta_{1+2} = (\theta_1 + \theta_2) - (\theta_1 \theta_2)$
 θ_1 = surface coverage by anion
 θ_2 = surface coverage by cation

θ_{1+2} = measured surface coverage by both the anion and the cation

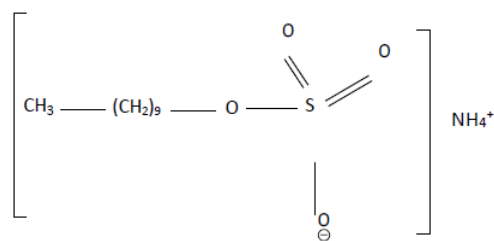
S_6 values nearly equal to unity which suggests that the enhanced inhibition efficiencies caused by the addition of these anions to surfactants is due to mainly to the synergistic effect.

III. RESULTS AND DISCUSSIONS:

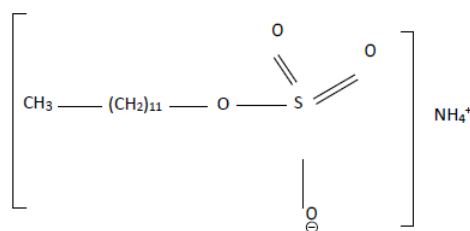
SADS,SADDS,SAHDSandSADDBSSasCorrosioninhibitorforCarbonSteel

Corrosion is defined as the loss of beneficial properties of materials and their alloys due to the attack of atmospheric gases on the metal surface. Air and humidity are two important factors in the initiation of corrosion of metal alloys. Dry corrosion and wet corrosion are two types of corrosion encountered by metals and their alloys. Wet corrosion is also called electrochemical corrosion. This is due to the formation of local anodes and cathodes. There are many factors that affect the corrosion rate. Various corrosion protection methods are available for different metals and alloys and for different conditions. Carbon steel is the main material of the body of buildings, household appliances, many tanks and water tanks, and is directly exposed to the corrosive environment during storage and use. Carbon steel needs corrosion protection in harsh environments. There are many ways to protect carbon steel from corrosion, such as painting, hot dip galvanizing, and combinations of these methods. If more sensitive materials are used, there are many methods that can be used to prevent damage to the product during its manufacture and use. The most corrosion resistant materials are thermodynamically undesirable corrosion. All corrosion products of gold or platinum spontaneously decompose into pure metal, so these elements can be found on earth in metal form and form a large part of the required production values. The more "basic" metal can be protected from time to time by various methods. Normal metals have slow reaction kinetics, but their corrosion is thermodynamically favored. These include metals such as zinc, magnesium and cadmium. Although corrosion of this metal is continuous, it occurs slowly. A great example of this is graphite, which releases a lot of energy when oxidized, but has very slow kinetics and is therefore well protected against electrochemical corrosion under normal conditions. Carbon and mild steel are the best metal materials used for the design and manufacture of products in many industries and modern life. Carbon monoxide and small metals corrode severely when exposed to a corrosive environment. However, their use is still mostly due to their low cost and quality. Stainless steel is widely used in kitchens, sinks, nuts and bolts, engine parts, etc. widely used. Metal is an attractive material for engineering due to its unique properties such as low cost, flexibility and durability. Corrosion protection for metals and alloys of organic compounds is the result of organic molecules or ions adsorbed on the metal

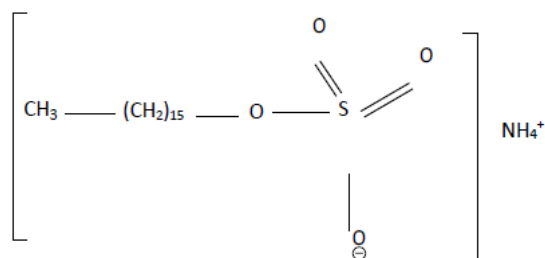
surface through adsorption sites to form a protective layer. This coating reduces or prevents corrosion of the metal. The rate of adsorption of organic corrosion inhibitors to the metal surface depends on many factors such as the nature of the metal, the state of the metal surface, the adsorption process, the chemical structure of the corrosion inhibitor and the type of corrosive system. [1] It is very important to add an anti-corrosion agent to reduce the breakdown of metal in acid. Therefore, many reports have been published on the use of organic chemicals as corrosion inhibitors to prevent corrosion of carbon steel in different corrosive environments [2-6]. The study reported in the paper was to investigate the effectiveness of a certain number of surfactants. Ammonium decyl sulfate (SADS), ammonium dodecyl sulfate (SADDS), ammonium hexadecyl sulfate (SAHDS) and ammonium dodecylbenzenesulfonate (SADDBS) as carbon steel Corrosion inhibitor in acidic environment. The effect of concentration and temperature on the corrosion inhibiting efficacy of research surfactants as carbon steel corrosion inhibitors was also evaluated. The effect of different surfactants on the corrosion of carbon steel is measured at 1.0 M HCl in the presence and absence of surfactants in the concentration range (20 to 150 ppm) by weight loss and electrochemical polarization processes. competence. The name and molecular structure of carbon steel anti-corrosion anionic surfactant in acidic medium are as follows:



(a) Decyl sulphate ammonium salt (SADS).



(b) - Dodecyl sulphate ammonium salt (SADDS).



(c) - Hexadecyl sulphate ammonium salt (SAHDS).

(d) - Dodecyl benzene sulfonate ammonium salt (SADDBS).

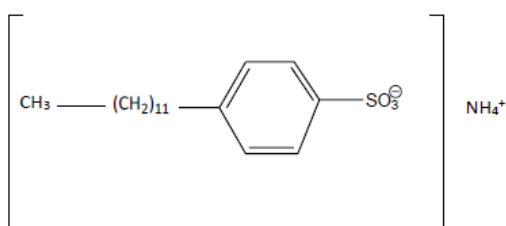


Figure:1

IV. Results and Discussion:

Table 2 gives the values of percentage corrosion inhibition efficiency for different concentrations of investigated surfactant compounds at 30 °C. Figure 2 shows percentage corrosion inhibition efficiency of all the four investigated organic surfactant molecule for carbon steel at 30.0 °C in presence of 1.0 M hydrochloric acid solution. It is clear from the Table 2 and Figure 2 that the weight loss decreased, percentage corrosion inhibition efficiency increased and therefore the corrosion inhibition strength increased with increase in inhibitor concentration from 20 to 150 ppm. This may be due to the increase in adsorption and surface coverage with increase in concentration of surfactant molecule. Thus, the surface is protected from the corrosive environment [7-8]. It is clear from Tables 2 that percentage corrosion inhibition efficiency increases with increase in inhibitor concentration. The percentage corrosion inhibition efficiency for different investigated anionic surfactants as corrosion inhibitor increases in the following order SADS > SADDS > SAHDS > SADDBS.

Table

3 gives the values of percentage corrosion inhibition efficiency for different concentrations of investigated surfactant compounds and 1.0×10^{-3} m KMnO_4 . Figure 3 shows synergistic effect of KMnO_4 on the percentage corrosion inhibition efficiency of all the four organic surfactant molecule for carbon steel at

30.0 °C in 1.0 M hydrochloric acid solution. It is observed from the Table 3 and Figure 3 that the addition of KMnO_4 improves the percentage corrosion inhibition efficiency of the investigated compounds significantly.

Table 4 shows typical current-potential of carbon steel in 1.0 M HCl in the absence and presence of various concentrations of organic surfactant. Values of associated electrochemical parameters such as current density (i_{corr}), corrosion potential (E_{corr}), Tafel slopes, and corrosion inhibition efficiency (per cent) as function of compound d concentrations in 1.0 M HCl are given in Table 4. It is evident from this Table 4 that the Tafel constants did not change significantly with increase in concentration of the surfactant molecule. Surfactant molecule acts as mixed type of corrosion inhibitor because they enhance the anodic and cathodic processes to the same extent but the anode is more polarized when an external current was applied. Addition of surfactant compounds to the system increases both cathodic and anodic over potential (OCP) and caused mainly equal shift in negative and positive direction, respectively. The temperature has great influence on the rate of corrosion. The effect of temperature on the corrosion behavior of carbon steel was also investigated for all the four surfactant molecule by weight loss method in the temperatures range of 30 to 50 °C with and without of different concentrations of compound (d) in 1.0 M HCl media and percentage corrosion inhibition efficiency of compound (d) is shown in Table 5. Figure 4 shows the effect of increasing temperature i.e. 30 to 50 °C on percentage corrosion inhibition efficiency of surfactant SADDBS in case of carbon steel. It is obvious from the Table 5 and Figure 4 shows that Percentage Corrosion Inhibition Efficiency (PCIE) increases with the change in the concentration of compound (d) (SADDBS) in positive direction and decreases with increasing the temperature. This proves that the increase of temperature results to the decrease in the surfactant adsorption and therefore the acceleration of the metallic corrosion in acidic medium [9-13].

The calculated values of the apparent activation energy, E^* , activation enthalpies, H^* and activation entropies, S^* are given in Table

5. Figure 4 shows activation parameters i.e. activation energy, change in enthalpy and change in entropy for carbon steel in case of surfactant D at different concentrations. The addition of surfactant molecule modified the values of E^* . This suggested that the process of corrosion is activation controlled.

This is in agreement with reports of different researchers [14-17]. The entropy change in the activation process (S^*) in the blank and inhibited solutions is large and negative indicating that the activated complex represents association rather than dissociation [18-20]. Mechanism of corrosion inhibition of all the four investigated organic surfactants can be explained on the basis of the shape, molecular size, chain length and the number of adsorption center present in the molecule. Organic

surfactant compound (SADDBS) in the present study, should be the most effective inhibitors, in spite of it has two active adsorption centers. The high percentage corrosion inhibition efficiency of the compound (SADDBS) may be due to its large size, or due to its benzene ring which contributes p electrons to the adsorption centers. Order of percentage corrosion inhibition efficiency $a < b < c$ and this agrees with their molecular size.

Table 2 Percentage corrosion inhibition efficiency at different concentrations of anionic surfactant for the corrosion of carbon steel after immersion in 1.0 M HCl at 30.0 °C.

Conc. of Surfactant (ppm)	Percentage Corrosion Inhibition Efficiency of Surfactants			
	(SADS)	(SADDS)	(SAHDS)	(SADDBS)
20	72.1	74.5	76.3	78.2
40	77.3	79.1	82.5	80.1
60	81.5	86.2	88.4	83.5
80	83.1	87.1	90.5	85.8
100	84.6	90.4	92.6	94.3
150	87.2	91.6	93.0	95.2

Table 3 Percentage corrosion inhibition efficiency at different concentrations of the four investigated surfactants (a to d) with addition of 1.0×10^{-3} M $KMnO_4$ for the corrosion of carbon steel after 24 hours of immersion in 1.0M HCl at $30^\circ C$.

Conc. of Surfactant (ppm)	Percentage Corrosion Inhibition Efficiency of Surfactants			
	(SADS)	(SADDS)	(SAHDS)	(SADDBS)
20	74.2	76.3	78.5	80.2
40	78.5	81.6	84.2	85.3
60	84.6	88.1	90.3	91.2
80	85.2	89.5	92.1	94.6
100	86.3	92.3	94.0	95.3
150	88.5	94.6	95.6	95.7

Table 4 The effect of concentrations of compound (d) on the free corrosion potential (E_{corr}), corrosion current density (i_{corr}), % age corrosion inhibition efficiency and degree of surface coverage (q) for the corrosion of carbon steel in 1.0M HCl at $30^\circ C$.

Conc. of Surfactant (d) (ppm)	$-E_{corr}, mV$	$i_{corr}, (\mu A/cm^2)$	q	Percentage CIE
Blank	699	83.9	-	-
20	649	33.2	0.70	77.7
40	644	30.1	0.72	80.6
60	635	27.4	0.74	84.0
80	634	25.3	0.80	86.1
100	630	23.0	0.89	94.7
150	624	19.6	0.93	95.8

Table 5 The effect of temperature on the corrosion inhibition efficiency of organic surfactant (SSDBS) at different concentrations and temperatures.

Concentration of Surfactant (d) (ppm)	$30^\circ C$	$40^\circ C$	$50^\circ C$
20	75.9	60.7	49.1
40	78.4	64.3	53.6
60	79.2	67.4	56.5
80	81.7	69.0	58.2
100	82.5	71.3	60.1
150	83.8	72.2	61.6

Table 6 Activation parameters of the corrosion of carbon steel in 1.0M HCl in absence and presence of different concentrations of compound (SADDBSS).

Conc. of Surfactant (d) (ppm)	E_a^* ($kJmol^{-1}$)	ΔH^* ($kJmol^{-1}$)	$-\Delta S^*$ ($Jmol^{-1}K^{-1}$)
20	61.31	61.53	183.72
40	64.78	63.42	175.23
60	67.34	65.75	167.92
80	68.41	68.38	162.14
100	70.64	71.81	156.04
150	75.85	73.15	147.43

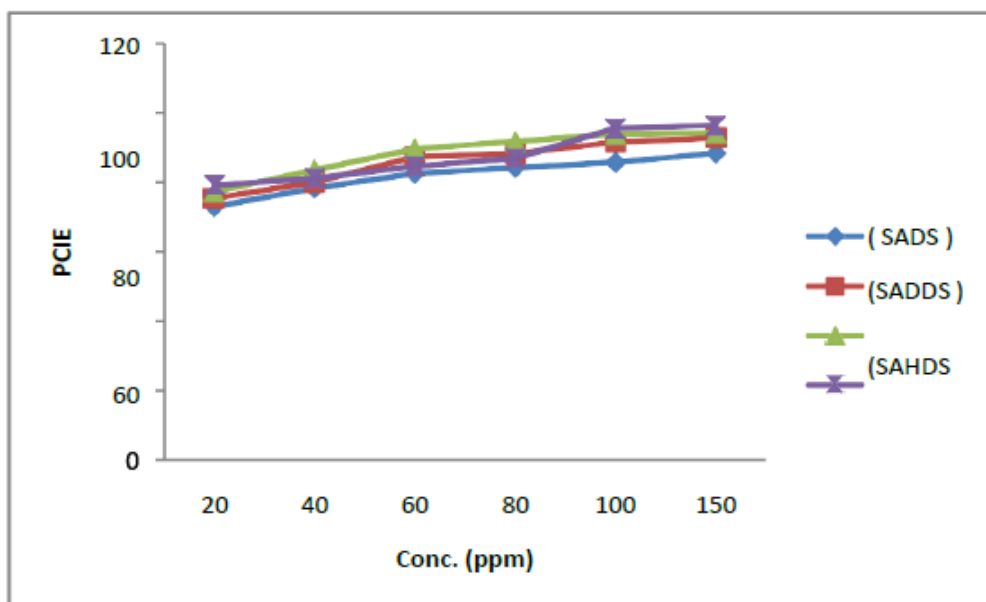


Figure 2 Percentage corrosion inhibition efficiency of all the four organic surfactants for Carbon steel at 30°C in presence of 1.0M hydrochloric acid solution.

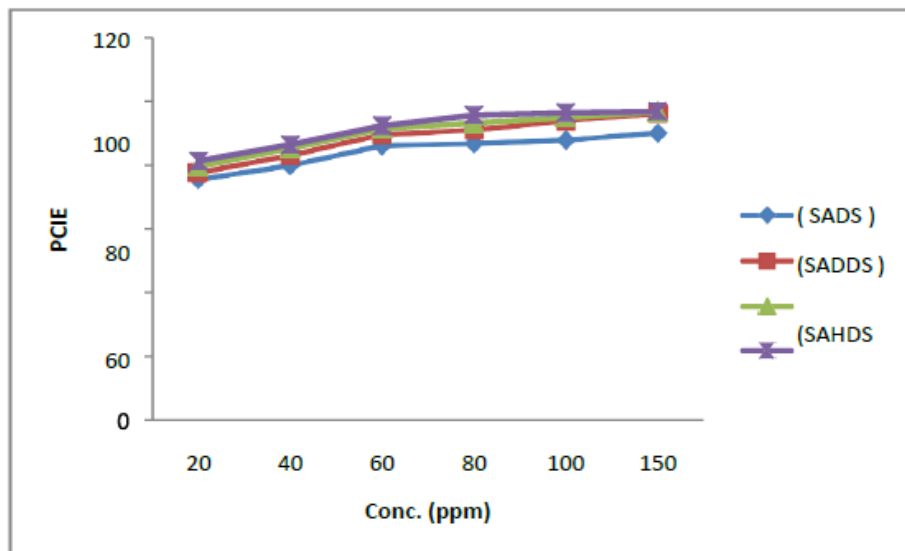


Figure 3 Synergistic effect of $KMnO_4$ on the percentage corrosion inhibition efficiency of all the four organic surfactants for carbon steel at $30^\circ C$ in 1.0M hydrochloric acid solution.

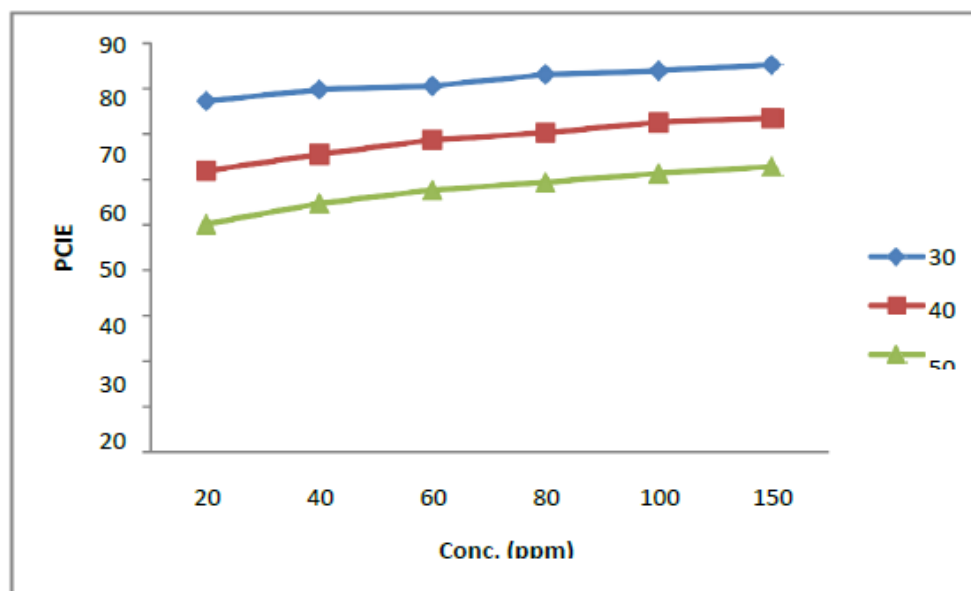


Figure 4 Effect of increasing temperature i.e. 30 to $50^\circ C$ on percentage corrosion inhibition efficiency of surfactant SADBSS in case of carbon steel.

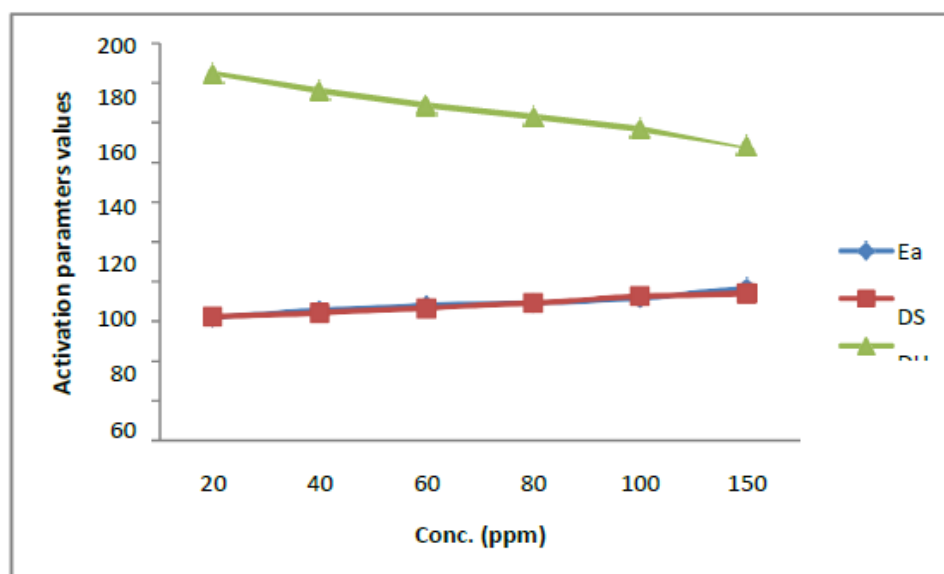


Figure 5 Activation parameters i.e. Activation Energy, change in Enthalpy and change in Entropy for Carbon Steel in case of surfactant SADBSS at different concentrations.

V. Conclusions:

Four different organic surfactant molecules were tested as corrosion inhibitors for carbon steel in acidic environment at 30°C. The four organic surfactant molecules acted as corrosion inhibitors for carbon steel in hydrochloric acid solution and corrosion inhibition efficiency values as surfactant. is increasing. the concentration increases from 20 ppm to 150 ppm. Surfactant molecules change the rate of activation energy, which also has some effect on the rate of corrosion resistance, so the decomposition of carbon steel in HCl solution is slower, and the mixture of metals in acidic environment is reduced. All four investigated organic surfactant molecules acted as hybrid corrosion inhibitors. Inhibition performance was demonstrated by electrochemical; polarization and weight loss are compatible with each other. An increase in temperature leads to a decrease in the corrosion of carbon steel in the HCl solution. It has been found that the addition of KMnO₄ to the corrosion inhibitor has less synergistic effect on the corrosion inhibitory effect of organic surfactants on metal.

References:

- [1]. Sastri V.S., Corrosion Inhibitors, 2003. John Wiley and Sons Chichester, p. 3.
- [2]. Bradford S.A., 2005. Corrosion Control, van Nostrand Reinhold, New York p.3.
- [3]. Kortum G. and Bockris J.O'M, 2001. Text Book of Electrochemistry, Elsevier, New York, Vol. 2, p. 745.
- [4]. Latimer W.M., 1997. Oxidation Potential, Prentice-Hall, New Jersey, p.39.
- [5]. LaQue F.L. and Cox G.L., 1940. Proc. Am. Soc. Testing Materials, **40**; 670. and LaQue F.L. and Copson N.R., 1995. Corrosion Resistance of Metal and Alloys, 2nd Ed. Reinhold Pub. Corp., New York.
- [6]. Hackerman N. and Hurd R.M., 1992. Proc. 1st Int. Congress on Metallic Corrosion, London p. 166.
- [7]. Pandya R.P., Langalia J.K., Mehta P.R., Bhat G.D. and Taqui Khan M.M., 1987. Proc. 10th Int. Congress on Metallic Corrosion, Madras, India, **3**; 2849-2859.
- [8]. Sekine I. and Hirakawa Y., 1986. *Corrosion*, **42**; 272.
- [9]. Veres A., Reinhard G. and Kalman E., 1992. *Brit. Corrosion J.*, **27**; 147.
- [10]. Kalman E., Varhegyi B., Bako I., Felhosi L., Karman F.H. and Shaban A., 2004. *J. Electrochem. Soc.*, **141**; 3357.
- [11]. Galkin T., Kotenev V.A., Arponen M., Forsen O. and Ylasaari S., 1995. Proc. 8th Euro. Symp. on Corrosion Inhibitors, Ferrara, Italy Vol. 1 p. 25.
- [12]. Rajendran S., Apparao B.V. and Palaniswamy N., EUROCORR'96 Nice, Paper No. II-p. 1.
- [13]. Hirozawa S.T., 1995. Proc. 8th Euro. Symp. on Corrosion Inhibitors, Ferrara, Italy, Vol. 1 p. 25.
- [14]. Galkin T., Forsen O., Ylasaari S., Kotenev V.A. and Arponen M., EUROCORR'96 Nice, Paper No. II-OR2.
- [15]. Rajendran S., Apparao B.V. and Palaniswamy N., 1996. Bull. Electrochem.

- em.,**12**;15.
- [20]. RajendranS.,ApparaoB. V.andPalaniswamyN.,1996.Proc.2ndArabianCorrosionConference,Kuwait p. 483.
- [21]. FangJ.L.,LiY.,YeX.R.,WangZ.W.andLiuQ.1993.*Corrosion*,49266.
- [22]. RajendranS.,ApparaoB. V.andPalaniswamyN.,1995.Proc.8thEuro.Symp.onCorrosionInhibitors,Ferrara,Italy**1**;465.
- [23]. GoodR.B.,1983.*MaterialsPerformance*,**22(9)**; 29.
- [24]. VanloyanD.,1989.*WerkstoffeandKorrosion*,**40**;599.