Synthesis and Surface Properties of Some Prepared Cationic Surfactants

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Abstract: In this study, three cationic surfactants have different alkyl chain length were synthesized and characterized by FTIR and ^{1}HNMR spectroscopy. The surface properties of the prepared surfactants were determined by surface tension measurements. The corrosion inhibition of the prepared compounds on the carbon steel in 1 M HCl solution was investigated by weight loss technique. The test was done at different concentrations and temperatures. The Thermodynamic parameters and activation energy of adsorption processes were calculated and discussed. The Biocidel effect of the prepared compounds was investigated against some Gram positive and Gram negative bacteria and fungi. It was found that the prepared compounds are good corrosion inhibitors and have high corrosion inhibition; the efficiency of these compounds increases with the inhibitor concentration. Mean while, it decreased with the tested temperature.

1. Introduction

Surfactants are compounds that can be found in a multitude of do mains, from industrial settings to research laboratories and are the part of our daily lives. Due to their unique structure, they can drastically modify the interfacial properties. This effect is important for industrial processes such as flotation, the cosmetic and food industries, drugs delivery, emulsification, chemical mechanical polishing, as also for corrosion inhibition [1].

It is well known that iron and iron-based alloys are used most widely in industry. Consequently, great attention has been paid to studies on the pitting of iron and its alloys.

The use of hydrochloric acid in pickling of metals, acidization of oil wells and in cleaning of scales is more economical, efficient and trouble-free, compared to other mineral acids [2,3]. Inhibitors are used to prevent metal dissolution as well as acid consumption [4,5].

Most well-known acid inhibitors are organic compounds containing nitrogen, sulfur, and oxygen atoms. Corrosion inhibitors are such substances that minimize or prevent corrosion if they are added at low concentrations in an aggressive environment. Selection of effective corrosion inhibitors is very important for an application in which inhibitors are selected regarding what kind of metal or alloy and corrosive environment are used. Effectiveness of the organic inhibitors depends on their adsorption rates and covering capabilities on metal surfaces. It has been realized from many sources that adsorption depends on the molecular structure, surface charge of

a metal and type of electrolytes. Inhibitors adsorbed by the metal surface immerse in an aqueous phase replacing water molecules adsorbed by the surface. Electrostatic interactions between an inhibitor molecules and a metal are prominent during this action of inhibitors. Electron densities of different functional group or groups, polarizability and electronegativity are main factors in this interaction. Consequently, a lot of organic compounds with suitable structures including heteroatom's such as P, S, N, or O can be widely used as corrosion inhibitors. These inhibitors bind on a metal surface with their functional groups and the backbone of the inhibitor molecules cover the metal surfaces.

The surfactant inhibitor has many advantages such as high inhibition efficiency, low price, low toxicity and easy production [6-10]. The adsorption of the surfactant on the metal surface can markedly change the corrosion-resisting property of the metal [11-12], and so the study of the relationship between the adsorption and corrosion inhibition is of great importance. Ionic surfactants have been used for the corrosion inhibition of iron [13-20], copper [21-24], aluminum [25-28] and other metals [29-30] in different corroding media.

The objective of the present work is to investigate the corrosion inhibition by N,N-bis(2-hydroxyethyl)-N-(2-(alkyloxycarbonyloxy)ethyl)-hexadecane-1-aminium bromide in 1 M HCl, so as to further study the inhibitive mechanism of the prepared inhibitors for carbon steel in hydrochloric acid. Gravimetric measurements were used. In addition, surface parameters were used to identify the

compounds properties. Also, is to investigate the biocide effect of the prepared surfactants against some bacteria and fungi.

2. Materials and Experimental Techniques:
2.1. Synthesis of cationic surfactant:
The target compounds were prepared through two steps. In the first step, the ester compounds were synthesized by reaction of triethanol amine and different fatty acids (dodecanoic acid, tetradecanoic acid and hexadecanoic acid), the molar ratio is 1:1, the reaction carry out in presence of xylene as solvent and p-toluene sulfonic acid as dehydrating agent, the product is 2-(bis(2-hydroxyethyl)amino)-ethyl alkyl ester. The reaction was completed when the water was removed from reaction system and its concentration was 1 mol. The reaction mixture was distilled under vacuum to remove the solvent.

In the second step, the end products were prepared by a reaction of hexadecyl bromide with appropriate amount of 2-(bis(2-hydroxyethyl)amino)-ethyl alkyl ester in the molar ratio of 1:1 to produce N,N-bis(2-hydroxyethyl)-N-(2-(alkyloxycarbonyl-oxy)ethyl)hexadecan-1-aminium bromide. The reactants were allowed to reflux in ethanol for 12 h. Then the reaction mixture was left to cool to room temperature. The chemical structures of the synthesis inhibitors designated as I, II and III are shown in scheme 1.

The chemical structure of the synthesized compounds was characterized by FTIR and ^{1}HNMR spectroscopic analyses.

2.2. Solutions:
The aggressive solutions, 1 M HCl, were prepared by dilution of analytical grade 37% HCl with distilled water. The concentration range of the prepared cationic surfactants used from 1×10^{-5} to 5×10^{-3} M for corrosion measurements and from 1×10^{-4} to 5×10^{-3} M for both surface tension and conductivity measurements. All solutions were prepared using distilled water.

The chemical structure and the abbreviations of the prepared compounds were illustrated in table 1.

2.3. Surface Tension Measurements:
Surface tension value of the solutions was measured with a Du Nouy Tensiometer (Kruss Type 6) for different concentrations of synthesized cationic surfactants. Doubly distilled water from an all-glass apparatus with a surface tension of 72 mN cm^{-1} at 25 °C was used to prepare all solutions.

2.4. Weight loss measurements:
The carbon steel sheets of 3 cm x 7.5 cm x 0.5 cm were abraded with a series of emery paper (grade 320-500-800-1000-1200) and then washed with bidistilled water and acetone.

After weighing accurately, the specimens were immersed in 100 ml closed beaker, which contained 100 ml 1 M hydrochloric acid with and without addition of different concentrations of inhibitors. After 24 h, the specimens were taken out, washed, dried and weighed accurately. Experiments were carried out in triplicate. The average weight loss of three parallel carbon steel sheets was obtained.

2.5. Antimicrobial activity:
The synthesized compounds were evaluated for their antimicrobial activity using the agar diffusion technique **(Cooper, 1972).** 1 mg/ml solution in dimethyl formamide was used. The tested organisms were Gram-negative bacteria (*Escherichia coli*, NCTC-10416 & *Pseudomonas aerogenasa*, NciB9016), Gram-positive bacteria (*Bacillus subtilis*, NCIB-3610 & *Staphylococcus aureus*, NCTC-7447) and fungi (*Aspergillus niger*, ferm-BAM C-21) and unicellular fungi as *Candida albicans.* The bacteria and fungi were maintained on nutrient agar medium and Czapeks Dox agar medium, respectively. DMF showed no inhibition zones. The agar media were inoculated with different test microorganism. After 24 h of incubation at 30 °C for bacteria and 48 h of incubation at 28 °C for fungi, the diameter of inhibition zone (mm) was measured.

3. Results and discussion:
3.1. Chemical structure:
The chemical structure of the prepared cationic surfactants was confirmed by the FTIR and ^{1}HNMR spectra and is shown in Figs. 1-2.

3.1.1. FTIR spectroscopy:
FTIR spectra of the synthesized compounds (Fig. 1) showed the following absorption bands at 722 cm^{-1} (CH$_2$ rocking), 1316 cm^{-1} (CH$_2$ deformation) 2916-2848 cm^{-1} (CH$_{st}$), 3149, 1028 cm^{-1} (C-N$^+$), 1716 cm^{-1} (O-C=O) and 3466 cm^{-1} (OH). The FTIR spectra confirmed the expected function groups in the synthesized cationic surfactants.

3.1.2. ^{1}HNMR spectroscopy:
^{1}HNMR spectra of the synthesized compounds (Fig. 2) showed different bands at δ=0.80 ppm (t, 3H, NCH$_2$CH$_2$(CH$_2$)$_n$CH$_2$C**H**$_3$); δ=1.18 ppm (m, 2H, NCH$_2$CH$_2$(CH$_2$)$_n$C**H**$_2$CH$_3$); δ=1.13 ppm (m, nH, NCH$_2$CH$_2$(C**H**$_2$)$_n$CH$_2$CH$_3$); δ=1.43 ppm (m, 2H, NCH$_2$C**H**$_2$(CH$_2$)$_n$CH$_2$CH$_3$); δ=3.07 ppm (t, 2H, NC**H**$_2$CH$_2$(CH$_2$)$_n$CH$_2$CH$_3$); δ=2.46 ppm (d, 2H, OCOC**H**$_2$CH$_2$(CH$_2$)$_n$CH$_2$CH$_3$); δ=3.39 ppm (d, 2H, NC**H**$_2$CH$_2$OH); δ=3.63 ppm (d, 2H, NCH$_2$C**H**$_2$OH); δ=3.44 ppm (s, 1H, NCH$_2$CH$_2$O**H**); δ=5.19 ppm (d,

2H, $NCH_2C\underline{H}_2OCOCH_2$). The data of ^{1}HNMR spectra confirmed the expected hydrogen proton distribution in the synthesized cationic surfactants.

All prepared compounds have the same signals. The only difference between the signals of these compounds is the signal intensity of methylene proton (m, nH, $NCH_2CH_2(C\underline{H}_2)_nCH_2CH_3$), where the intensity of this signal increases by increasing the methylene groups (chain length) of the prepared compounds.

3.2. Surface active parameters:
3.2.1. Surface tension (γ) :
The variation of the surface tension γ values obtained for different concentrations of aqueous solutions of the prepared surfactants is represented in Fig. 3. Sharp decrease in surface tension values is observed as the activity (concentration) increases and then the curves break rather rapidly at still relatively low concentrations and continue to decrease slowly as the concentrations increase. The critical micelle concentration (CMC) was determined from the intersection points in the γ–log C curves, (Table 2). The obtained CMC values of the synthesized surfactants show a decreasing trend with increasing hydrophobic moiety. This can be accounted for decrease hydration of the hydrophilic part, which favors micellization.

3.2.2. Effectiveness (Π_{CMC}):
The surface tension values (γ) at CMC were used to calculate values of the surface pressure (effectiveness) from equation [31]:
$$\Pi_{CMC} = \gamma_o - \gamma \qquad (1)$$
where γ_o is the surface tension measured for pure water at the appropriate temperature and γ is the surface tension at critical micelle concentration. The values of Π_{CMC} of the prepared surfactant are listed in Table 2. The most effective surfactant is one that gives the greater lowering in surface tension for a critical micelle concentration (CMC). According to the results listed in Table 2, compound (III) is the most effective surfactant.

3.2.3. Surface excess (Γ_{max})
According to Gibb's equation [32]:
$$\Gamma_{max} = - (d\gamma/d \log C)_T / (2.303nRT) \qquad (2)$$
where dγ/dlog C is the surface pressure, R is the universal gas constant, T is the absolute temperature and value of n is taken as 2 for a cationic surfactant [33].

A substance that lowers the surface energy is thus presents in excess at or near the surface, i.e. when the surface tension decreases with increasing activity of a surfactant. The values of Γ_{max} were calculated and listed in Table 2. Increasing the

hydrophobic character of the cationic surfactants shifts Γ_{max} to lower concentrations.

3.2.4. Minimum surface area (A_{min})
The minimum surface area is defined as the area occupied by each molecule in nm^2 at the liquid/air interface. The minimum surface area occupied by each surfactant molecule at the air/water interface (A_{min}) is calculated according to the following equation [34]:
$$A_{min} = 10^{16}/N. \Gamma_{max} \qquad (3)$$
where Γ_{max} is the maximum surface excess and N is Avogadro's number.

The minimum area per molecule at the aqueous solution/air interface increases with increasing length of the hydrophobic part. Analysis of data, listed in Table 2, indicates that the surface pressure Π_{CMC} of the prepared surfactants decreases with increasing minimum surface area A_{min} of the surfactant molecule.

3.4. Standard free energy (ΔG_{mic})
In the charged pseudo-phase model of micelle formation, the standard free energy of micelle formation per mole of the synthesized surfactant was calculated by the following equation [35]:
$$\Delta G^o_{mic} = (2- \beta) RT \ln (CMC) \qquad (4)$$
where R is the gas constant, T the temperature and CMC is expressed in the molarity of the surfactant.

Obviously, the standard free energies of micellization for the synthesized surfactants are always negative, indicating that the micellization is a spontaneous process. The free energy change ΔG_{mic} (CH_2) involved in the transfer of a methylene group from an aqueous environment to the interior of the micelle is negative, thus favoring micellization. This is due to the fact that CMC decreases with increasing length of the hydrophobic group, i.e. introduction of additional methylene groups induces micellization.

3.5. Weight loss measurements:
The corrosion rate (k) was calculated from the following equation [36]:
$$k = (W/St) \qquad (5)$$
where W is the average weight loss (mg) of three parallel carbon steel sheets, S the total area of the specimen (Cm^2) and t is the immersion time, (hr). From the calculated corrosion rate, the inhibition efficiency (η_w %) and surface coverage (θ) of inhibitors on surface of carbon steel was calculated using the following equations [37,38]:
$$\eta_w \% = ((k^o- k)/ k^o) \times 100 \qquad (6)$$
where k^o and k are the values of the corrosion rate with and without inhibitor, respectively.
$$\theta = (k^o - k)/ k^o \qquad (7)$$

The corrosion parameters such as corrosion rate (k), inhibition efficiency (η_w %) and surface coverage (θ) at different concentrations of the synthesized surfactants in 1 M HCl at 25 ^{o}C are listed in Table 2. As can be seen in Table 3, the synthesized surfactants inhibit the corrosion of carbon steel at all concentrations in 1 M HCl. Inspection of these data in Table 3, reveals that the inhibition efficiency increases with increasing the concentration of the synthesized inhibitors and that compound (III) is better inhibitor than both compound (I) and compound (II).

Fig. 5 shows the relation between η_w % and logarithm of the concentration of the prepared inhibitors.

3.6. Adsorption isotherm

It has been assumed that organic inhibitor molecules establish their inhibition action via adsorption of the inhibitor onto the metal surface. The adsorption processes of the inhibitor are influenced by the chemical structure of organic compounds, nature and surface charge of the metal, the distribution of the charge in the molecule and type of aggressive media.

In general, two modes of adsorption can be considered. The proceeding of physical adsorption requires presence of electrically charged metal surface and charged species in the bulk of the solution. Chemisorption process involves charge sharing or charge transfer from the inhibitor molecules to the metal surface. The presence of an inhibitor molecule having relatively loosely bound electrons or heteroatoms with lone-pair electrons with a transition metal having vacant and low-energy electron orbital facilitates this adsorption [39].

Assuming the corrosion inhibition was caused by the adsorption of the synthesized surfactants and the values of surface coverage (θ) for different concentrations of inhibitors in 1 M HCl were evaluated from weight loss measurements from Eq. (7). Adsorption isotherms are very important in determining the mechanism of organic electrochemical reactions. The most frequently used adsorption isotherms are Langmuir. It was found that adsorption of the synthesized surfactants on carbon steel surface in HCl solution obeys Langmuir adsorption isotherm given by the following equations [40]:

$$C/\theta = 1/K_{ads} + C \qquad (8)$$
$$K_{ads} = 1/55.5 \exp(-\Delta G_{ads}/RT) \qquad (9)$$

where C is the inhibitor concentration, θ is the fraction of the surface covered, K_{ads} is the equilibrium constant of the inhibitor adsorption process, the value 55.5 is the molar concentration of water in solution in mol dm^{-3}, R is the gas constant, T is absolute

temperature and ΔG_{ads} is the standard free energy of adsorption process.

Fig. 6 shows the dependence of the fraction of the surface covered C/θ as a function of the concentration (C) of the synthesized inhibitors.

The adsorption equilibrium constant (K_{ads}) equal reciprocal intercept in Fig. 6 for cationic surfactants at different concentrations and temperatures was calculated and listed in Table 4. It was found that the high values of K_{ads} reflect the high adsorption ability of these inhibitors on carbon setel surface in 1 M HCl.

The negative value of ΔG_{ads} means that the adsorption of the prepared cationic surfactants on carbon steel surface is a spontaneous process and also show a strong interaction of the inhibitor molecule onto the carbon steel surface [41, 42].

Generally, values of ΔG_{ads} around −20 kJ mol^{-1} or lower are consistent with the electrostatic interaction between the charged molecules and the charged metal (physisorption). While those more negative than −40 kJ mol^{-1} involve charge sharing or transfer from the inhibitor molecules to the metal surface to form a coordinate type of bond (chemisorptions) [43,44]. The calculated ΔG_{ads} values indicated that the adsorption mechanism of the prepared cationic surfactants on carbon steel in 1 M HCl solution is a mixed from physical and chemical adsorption [45].

The adsorption heat can be calculated according to the Van't Hoff equation [45, 46]:

$$\ln K_{ads} = -\Delta H^o_{ads}/RT + constant \qquad (10)$$

where ΔH^o_{ads} and K_{ads} are the adsorption heat and adsorptive equilibrium constant, respectively.

It should be noted that $-\Delta H^o_{ads}/R$ is the slope of the straight line ln K_{ads}–1/T according to Eq. (10) and the molecular weight of inhibitor is also a positive constant, so the value of adsorption heat does not change with the unit of adsorptive equilibrium constant. The straight line ln K_{ad} –1/T is shown in Fig.7. Because the experiment was proceeded at the standard pressure and the solution concentration is so low that it is close to standard condition, the adsorption heat ΔH_{ads} can be approximately regarded as the standard adsorption heat ΔH^o_{ads} under such experimental conditions [47, 48]. The negative sign of ΔH^o_{ads} values for cationic surfactants indicated that the adsorption of inhibitor molecules was an exothermic process.

According to the thermodynamic basic equation, the standard adsorption entropy, ΔS^o_{ads}, was calculated from the following equation [49]:

$$\Delta G^o_{ads} = \Delta H^o_{ads} - T \Delta S^o_{ads} \qquad (11)$$

All the obtained thermodynamic parameters were given in Table 4. The positive ΔS^o_{ads} values for cationic surfactants was attributed to the increase of

disorder due to the adsorption of only one surfactant molecule by desorption of more water molecules [50].

3.7. Activation thermodynamic parameters

The activation energy of corrosion process with and without the inhibitor was calculated according to the following equation [51]:

k = A exp -E_a / RT   (11)

where E_a is the activation energy, A is the frequency factor, T is the absolute temperature, R is the gas constant and k is the rate of corrosion reaction.

The apparent activation energies (E_a) at different concentrations of inhibitors were calculated by using the linear regression between ln (k) and 1/T (Fig. 8), and also the results listed in Table 5. All the linear regression coefficients are close to one, indicating that the carbon steel corrosion in HCl can be elucidated using the kinetic model. Results in Table 5 show that the activation energy increased in presence of the inhibitors. The higher values of the activation energy were obtained in the presence of cationic surfactants when compared with those obtained in absence. This could be attributed to their physical adsorption on the carbon steel surface [52].

3.8. The relation between corrosion inhibition and surface properties of the prepared surfactants.

The greatest reduction of surface tension (effectiveness, Π_{CMC}) was achieved by compound (III) compared with that obtained by the other two surfactants. This is in good agreement with the inhibition efficiency results achieved by compound (III) (Tables 2-3).

It seems that the synthesized surfactants favor adsorption rather than micellization [53]. The fact that ΔG_{ads} is more negative compared with the corresponding ΔG_{mic} may be taken as a strong evidence for the more feasibility of the adsorption of the synthesized surfactants. It notes that Γ_{max} of both compound (I) and compound (II) lower than Γ_{max} of compound (III). On the other hand, A_{min} values of both compound (I) and compound (II) are higher than that of compound (III) considering this one explain why compound (III) is more effective than compound (I) and compound (II). The high value of Γ_{max} of compound (III) indicates that more numbers of molecules are adsorbed. This implies close packing of the adsorbed molecules associated with a less area on the metal surface for each molecule thus leading to more electrostatic interaction of the well packed adsorbed layer and more homogenous adsorbed film.

All these parameters explain why compound (III) is the most effective inhibitor.

3.9. Antimicrobial activity of the prepared cationic surfactants against SRB

The results of antimicrobial activity of the synthesized cationic surfactant against pasogenic bacteria and fungi were determined and listed in Tables 6&7. The results indicate that the synthesized cationic surfactants have antimicrobial activity against the tested microorganisms and their activities depend on their chemical structures (mainly the hydrophobic chain length). The optimal potency of the synthesized inhibitors was observed to the dodecyl chain (12-methylene groups). These results are in good agreements with the results of several investigators dealt with the cationic biocides [54]. The action mode of such cationic biocides on the different bacterial strains is explained as an electrostatic interaction and physical disruption. The electrostatic interaction is occurred between the oppositely charged centers on the cellular membrane and the positively charged head groups of the biocide molecules. While, physical disruption is occurred from the penetration of the hydrophobic chains into the cellular membrane due to the similarity in the chemical nature. The interaction between the biocide molecules and the cellular membrane cause a strong damage of the selective permeability of these membranes which disturbs the metabolic pathway within the cytoplasm [55].

Conclusions

From obtained results the following conclusion can be drown:

The prepared compounds were exhibited a good surface properties and CMC values were decreased with fatty chain length increasing.

The synthesized cationic surfactants have good corrosion inhibition for carbon steel in 1 M HCl. Their inhibiting properties increase with increasing its concentration. The inhibition has the following order: compound (III) > compound (II) > compound (I).

The investigated inhibitors were suggested to be mixed from physical and chemical adsorption on the steel electrode on the basis of the high values of the adsorption-desorption equilibrium constant, K_{ads}, and the free energy of adsorption, ΔG_{ads}, in addition, and the obedience of the adsorption to Langmuir's model.

The prepared surfactants were exhibited a good biocide properties against some bacteria and fungi

Table 1: The chemical structures and the abbreviation of prepared compounds

Structure	Abbreviation
$H_3C - (CH_2)_9 - CH_2 - C(=O) - OCH_2CH_2 - N^{+}(CH_2CH_2OH)(CH_2CH_2OH) - (CH_2)_{15}CH_3 \quad Br^{-}$	I
$H_3C - (CH_2)_{11} - CH_2 - C(=O) - OCH_2CH_2 - N^{+}(CH_2CH_2OH)(CH_2CH_2OH) - (CH_2)_{15}CH_3 \quad Br^{-}$	II
$H_3C - (CH_2)_{13} - CH_2 - C(=O) - OCH_2CH_2 - N^{+}(CH_2CH_2OH)(CH_2CH_2OH) - (CH_2)_{15}CH_3 \quad Br^{-}$	III

Table 2: The critical micelle concentration (CMC) and surface parameters of the synthesized cationic surfactants from surface tension measurements at 30 ^{o}C

Inhibitor name	CMC mol dm^{-3}	γ_{CMC} mN m^{-1}	Π_{CMC} mol dm^{-3}	Γ_{max} x 10^{11} mol cm^{-2}	A_{min} nm^{2}	ΔG_{mic} kJ mol^{-1}
I	0.007	33.0	39.0	5.53	3.00	-29.16
II	0.005	31.5	40.5	6.04	2.75	-29.86
III	0.002	29.0	43.0	6.22	2.67	-33.92

Table 3: The corrosion rate, surface coverage and inhibition efficiency of the synthesized inhibitors at different concentrations for carbon steel in 1.0 M HCl solution at 30 ^{o}C

Temp. ^{o}C	Conc. of inhibitor M	I k mg cm^{-2} h^{-1}	θ	η_w %	II k mg cm^{-2} h^{-1}	θ	η_w %	III k mg cm^{-2} h^{-1}	θ	η_w %
30	0.00	0.6157	-	-	0.6157	-	-	0.6157	-	-
	5 x 10^{-5}	0.1069	0.83	82.64	0.1545	0.82	81.89	0.2570	0.77	77.49
	5 x 10^{-5}	0.0918	0.85	85.09	0.1444	0.83	83.08	0.2220	0.81	80.56
	1 x 10^{-4}	0.0776	0.87	87.40	0.1211	0.86	85.80	0.1892	0.83	83.43
	5 x 10^{-4}	0.0645	0.90	89.53	0.0997	0.88	88.32	0.1581	0.86	86.15
	1 x 10^{-3}	0.0565	0.91	90.82	0.0860	0.90	89.92	0.1402	0.88	87.72
	5 x 10^{-3}	0.0441	0.93	92.84	0.0690	0.92	91.92	0.1143	0.90	89.98
40	0.00	0.8532	-	-	0.8532	-	-	0.8532	-	-
	5 x 10^{-5}	0.1013	0.84	83.55	0.1482	0.83	82.64	0.2477	0.78	78.31
	5 x 10^{-5}	0.0808	0.87	86.87	0.1361	0.84	84.05	0.1977	0.83	82.68
	1 x 10^{-4}	0.0645	0.90	89.53	0.1000	0.88	88.28	0.1600	0.86	85.98
	5 x 10^{-4}	0.0563	0.91	90.86	0.0865	0.90	89.86	0.1406	0.88	87.68
	1 x 10^{-3}	0.0459	0.93	92.55	0.0777	0.91	90.89	0.1217	0.89	89.34
	5 x 10^{-3}	0.0357	0.94	94.20	0.0593	0.93	93.05	0.0971	0.91	91.49
50	0.00	1.1416	-	-	1.1416	-	-	1.1416	-	-
	5 x 10^{-5}	0.0887	0.86	85.59	0.1386	0.84	83.76	0.2210	0.81	80.64
	5 x 10^{-5}	0.0739	0.88	88.00	0.1115	0.87	86.93	0.1886	0.83	83.48
	1 x 10^{-4}	0.0595	0.90	90.34	0.0931	0.89	89.09	0.1528	0.87	86.61
	5 x 10^{-4}	0.0469	0.92	92.38	0.0706	0.92	91.73	0.1220	0.89	89.31
	1 x 10^{-3}	0.0369	0.94	94.01	0.0622	0.93	92.71	0.0991	0.91	91.32
	5 x 10^{-3}	0.0279	0.95	95.47	0.0470	0.94	94.50	0.0816	0.93	92.85

Table 4: The thermodynamic parameters of adsorption of the synthesized inhibitors at different concentrations for carbon steel in 1.0 M HCl solution at 30 ^{o}C

Inhibitor name	Temp. ^{o}C	$K_{ads} \times 10^4$ (M^{-1})	ΔG^o_{ads} kJ mol^{-1}	ΔH^o_{ads} kJ mol^{-1}	ΔS^o_{ads} kJ mol^{-1}
I	30	9.01	-38.86		98.13
	40	8.26	-39.92	-9.13	98.37
	50	7.19	-40.82		98.12
II	30	10.20	-39.17		94.47
	40	8.93	-40.12	-10.55	94.47
	50	7.87	-41.06		94.47
III	30	11.10	-39.39		92.71
	40	10.40	-40.52	-11.29	93.37
	50	8.40	-41.24		92.70

Table 5: The activation energy values for carbon steel in 1.0 M HCl solution in the absence and presence of different concentrations of the synthesized inhibitors at 30 ^{o}C

Conc. of inhibitor M	ΔE_a kJ mol^{-1}		
	I	II	III
0.00	25.12	25.12	25.12
5×10^{-5}	35.62	36.30	37.13
5×10^{-5}	35.91	36.44	38.07
1×10^{-4}	36.27	36.97	38.37
5×10^{-4}	36.49	37.23	38.81
1×10^{-3}	36.93	39.72	40.25
5×10^{-3}	38.75	40.70	42.24

Table 6: Minimal Inhibitory Concentration (mg/ml)(M.I.C.) of the provided samples against test organisms

Test Organism / Sample No.	Minimal Inhibitory concentration (MIC) mg/ml				
	Bacillus subtillus	*E. coli*	*Staphylococcus aureus*	*Pseudomonas aeruginosa*	*Candida albicans*
C_{12}	0.312	0.312	0.625	0.078	0.312
C_{14}	0.312	0.625	0.156	0.312	0.312
C_{16}	0.078	1.25	0.312	0.312	0.625
St.	0.0195	0.0097	0.0195	0.00976	0.0391

St. = Standard is Amikacin.

Table 7: Antimicrobial activity of the prepared cationic surfactants on some organisms

Sample / Test Organism	*Bacillus subtillus*	*Staphylococcus aureus*	*Pseudomonas aeruginosa*	*E. coli*	*Candida albicans*
C_{12}	21	20	26.5	21	23
C_{14}	19.5	21	20.3	19	19.75
C_{16}	23.5	20.5	18.6	17	17
St.	29	31	32	34	25

The test was done using the paper disk technique.

Well diameter. 1 cm ….. (100 ul of each conc. was tested)
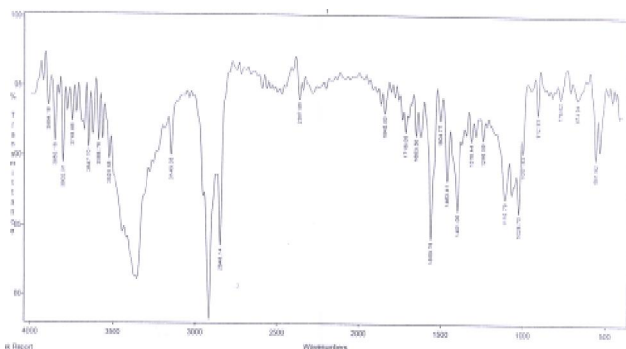
Inhibition zone (m.m)

St. = Standard is Amikacin.
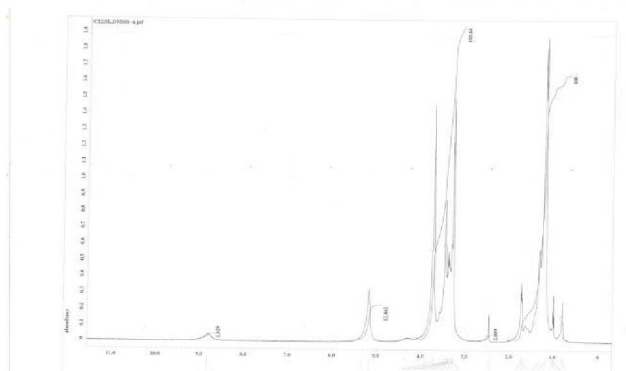
Fig. 1: The FTIR of Compound III
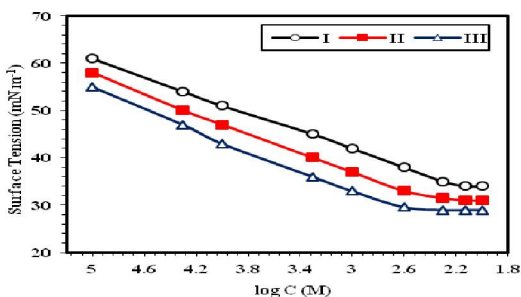

Fig. 2: HNMR of C16 Compound III

Fig. 3: Variation of the surface tension with the synthesized cationic surfactants concentrations in water at 25 °C
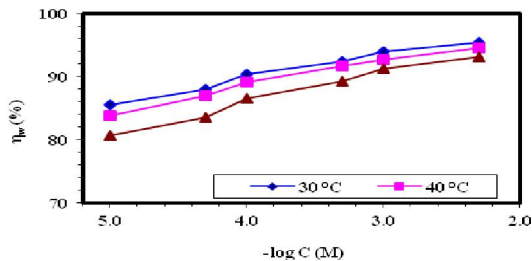

Fig 4: The variation of the inhibition efficiency of compound (III) obtained by weight loss method versus log (C) of cationic surfactants studied in 1 M HCl solution at different temperatures.
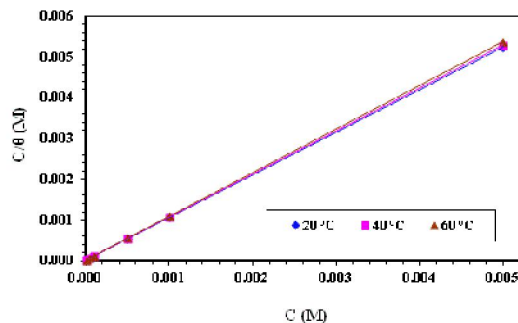

Fi g 5: Langmuir isotherm for adsorption of inhibitor (III) on the carbon steel surface in 1 M HCl at various temperatures
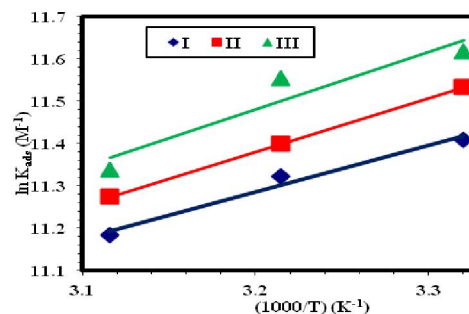

Fig 6: Arrhenius plots of ln k vs. 1/T for carbon steel in 1 M HCl in the absence and presence of different concentrations of the prepared inhibitors.
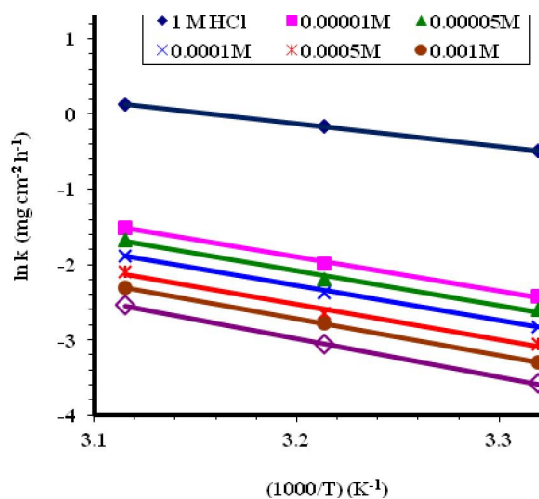

Fig 7: Arrhenius plots of ln k vs. 1/T for carbon steel in 1 M HCl in the absence and presence of different concentrations of compound (III).

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