Thi_Qar University Journal for Engineering Sciences, Vol. 2, No. 3 November 2011

Duplex Inhibition of CO2 Corrosion in Iraqi Oilfield

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Abstract

New method for inhibition CO**2** corrosion in Iraqi oilfield was used in this work. This new method included using combination of heat treatment of steel and added Aromatic (Tetrahydronaphthalene) compounds as corrosion inhibitor in different concentration (0.05%, 0.1%, 0.2%, 0.5% and 1%). The results referred that the weight loss was reduced as inhibitor concentration increased for all conditions of specimens whether, there were heat treated or not. The combination of annealing heat treatment of samples and using Aromatic compounds inhibitor offered a better corrosion resistance than the combination of quenching + tempering (Q+T) samples. The presence of inhibitor improves the corrosion resistance for annealed samples. For fully annealing, the weight loss was 5 times lesser than that for (Q+T) samples, while the weight loss of steel (as received condition) was 3 times lesser than that for (Q+T) samples.

Keywords : Inhibition, Oilfield, CO**2** corrosion, heat treatment, Aromatic (Tetrahydronaphthalene) , annealing, quenching , tempering weight loss, efficiency**.**

المستخلص

استخدمت في هذا البحث طريقة جديدة لحماية الفولاذ المستعمل في الحقول النفطية من التاكل بغاز ثاني اوكسيد الكربون. تتضمن الطريقة الجديدة حماية مزدوجة تعتمد على معاملة الفولاذ حراريا مع إضافة مثبط كيماوي إلى الوسط. استخدم نوعيين من المعاملات الحرارية . يتضمن النوع الأول تلدين النماذج بينما أجريت عملية تقسية + عملية مراجعة للنوع الثاني. استخدم مثبط كيماوي من تتراهيدرونفثالين وبتراكيز مختلفة هي:

. (0.05%, 0.1%, 0.2%, 0.5% and 1%)

أوضحت نتائج البحث إن الفقدان بالوزن يقل بزيادة تركيز المثبط ولجميع حالات النماذج المستخدمة سواء كانت معاملة حراريا أو غير معاملة. إن الحماية المزدوجة المنجزة بإجراء عمليات التلدين للنماذج مع إضافة المثبط الكيماوي أعطت نتائج أفضل من الحماية المزدوجة المنجزة عن طريق إجراء معاملات حرارية تتضمن التقسية + المراجعة مع إضافة المثبط الكيماوي. إن وجود المثبط الكيماوي يحسن مقاومة التآكل للنماذج اللدنة بمقدار خمسة مرات عما هي للنماذج التي أجريت لها عمليات تقسية ومراجعة بينما كان الفقدان بالوزن اقل ثلاث مرات للفولاذ غير المعامل حراريا مقارنة بالفقدان بالوزن للعينات التي اجري لها عمليات تقسية + مراجعة.

1. Introduction

Corrosion in the oilfield is defined as deterioration of a metal by chemical or electrochemical reaction with the environment. Low carbon steel is the most common metal that is utilized in oil and gas production [1-3]. CO_2 and H_2S gases in combination with water are the main cause of corrosion in oil and gas production. The most predominant form of corrosion encountered in Oil and Gas production is the one caused by CO_2 [3]. Carbon steel has low resistance to CO_2 environments, it is widely used in the petroleum industry mainly due to economical reasons [4]. What makes feasible the use of carbon steels is the natural precipitation of protective iron carbonate ($FeCO_3$) [5,6].

The oil and gas industry has been given much attention in recent years because of an increased tendency to inject CO_2 into oil wells to reduce the viscosity of oil and increase its production [3].

Carbon dioxide that dissolves in water lowers the pH of the water and increases the corrosion rate. The pH of the water will increase (because of CO_2 evolution) at lower pressures. It should be noted that calcium carbonate and calcium sulfate scales often occur at points where there is a drop in gas pressure [3, 4]. Carbon dioxide dissolves in water to form H_2CO_3 carbonic acid (H_2CO_3) is produced with the characteristic that is more aggressive than hydrochloric acid at the same pH [5]. Carbonic acid reacts directly with iron to form Fe_2CO_3. The reaction is: $H_2CO_3 + Fe \rightarrow FeCO_3 + H_2$

Inhibitor protection seems to be one of the most appropriate and cost efficient ways to address the CO2 Corrosion problem [6, 7]. The inhibitors applied during the operation of oil equipment and pipelines should satisfy a number of engineering requirements: they should be soluble or dispersible in water or brine, they should be easily separable, they should ensure a highly protective effect, they should prevent the formation of pitting, they should prevent the hydrogenation of steel (in the case of the presence of H_2S), and they should be non-toxic.

The more the inhibitor is maintained in the solution, the more the corrosion rate decreases up to a certain concentration which is defined as critical concentration of inhibitor. From the economical point of view, it is desirable to maintain the inhibitor level just on critical concentration, but the corrosion rate increases sharply if the inhibitor concentration become under critical value.

Selection of a particular corrosion inhibitor is usually made based on the f of corrosion, the type of production, prior experience, and laboratory or field testing [3]. Corrosion inhibitors which used for oil field applications are very complex compounds. The most effective corrosion inhibitors, which have been widely used, when carbon steels are exposed to CO_2 environments, can be sorted into four generic groups: amine imidazoline, amines and amine alts, quaternary ammonium salts, and nitrogen heterocyclics. Inhibitors fall into four general categories based on mechanism and composition. These categories are [4, 7]:

1- Barrier layer formation.
2- Neutralizing.
3- Scavenging.
4- Other environment modification.

Adsorption-type inhibitors are the most common barrier layer inhibitors. These inhibitors form a stable bond with the metallic surface. Typical examples of this type of inhibitor are organic phosphates and chromates. In general, these organic compounds are adsorbed and form a stable bond with the metal surface. The successful application of carbon steels in oil and gas pipelines and production tubular in CO_2 containing environments depends mainly on the formation of protective corrosion product film or the use of corrosion inhibitors [1-5]. Barrier layer formation inhibitors form a layer on the corroding metal surface, modifying the surface to reduce the apparent corrosion rate. They represent the largest class of inhibitive substances.

There are three standard treatment methods used for corrosion inhibition in oilfield [4, 7]. Continuous treatment, displacement treatment, and squeeze treatment. Continuous treatment involves continuous injection of corrosion inhibitor into the production stream. Treatment concentrations normally range between 5 – 15 ppm for liquid production depending on the concentration of the corroding. The treatment concentration for gas production may be as high as 100 ppm [3].

Displacement treatments involve filling the production tubing with corrosion inhibitor, allowing it to stay in contact with the tubing for a period of time (up to several hours) and then producing the inhibitor back through the production equipment. Squeeze treatments are similar to displacement treatments except that the corrosion inhibitor is pumped into the formation. These two treatment methods are usually used in wells with lower production rates.

The use of inhibitor in CO_2 corrosion of carbon and low alloy steels with different chemical composition or different microstructure are not recognized in the literature. These variables are independent; different inhibition can be obtained for different microstructure with addition of different inhibitor or different inhibitor concentrations. Some authors [1-3, 8] reported the effect of one of these parameters without taking into account that the other [5, 7, 9] has been also modified. Also the influence of microstructure on the inhibitors performance is still lacking.

The aim of the present work is to use new method for inhibition CO_2 corrosion in Iraqi oilfield. The new method included using combination of heat treatment of steel and added corrosion inhibitor at different concentrations. The effects of water content in oil and the effects of carbon steel microstructure on the efficiency of corrosion inhibitors in CO_2 environments is also considered in this work.

2. Experimental

2. 1 Material & specimen preparation

Carbon steel is the most commonly used materials in the fabrication and manufacturing of oil field operating platforms because of their availability, low cost, ease of fabrication, and high strength, therefore rectangular specimens of a carbon steel grade API 5L X65 were used in this research. These specimens were obtained from Kirkuk oilfield. The chemical composition of the investigated specimens was given in Table (1).

Table (1). Chemical compositions of carbon steel samples.

Element	C	Si	Mn	P	S	Cu	Ni	Cr	Fe
Wt%	0.08	0.32	1.47	0.016	0.004	0.10	0.10	0.03	Remains

The specimens were sequentially polished with 240, 320, 420 and 600 grit sandpaper. Then the specimens wash with running tap water followed by distilled water, dried with clean tissue paper immersed in acetone & further cleaned successively with in an ultrasonic bath for 2 minutes. The final dimensions of the specimen were 10mm x 20mm x100 mm.

2.2 Heat treatment

The heat treating procedures were as follows:

2.2.1 Annealing; the specimens were heated to 850 °C in a rotary –diffusion vacuum furnace type (Vacscal VS2) for one hour and then slowly cooled to room temperature.

2.2.2 Quenching; the specimens were heated to 850 °C in vacuum furnace for one hour and then quickly cooled in water bath to room temperature.

2.2.3 Tempering; the quenching specimens were tempered by raising the temperature to 430 °C in vacuum furnace for 2 hours and then slowly cooled down to room temperature.

2.3 Solutions

2.3.1 Solution composition

Table (2) showed the chemical composition of water produced with oil in Kirkuk oilfield from well no. K184. Sodium chloride concentration varied within the range 26000-27000 ppm. A sketch of oil field gathering system is shown in Figure (1).

Table (2). Chemical compositions of water produced with oil.

Component	NaCl	CaHCO3	CaSO4	CaCl2	MgCl2
Conc.(ppm)	26500	5670	3450	513	3780

In the present work, water simulation is based only on NaCl concentration of highest level 27000 ppm in distilled water by using equivalent weight of analar NaCl i.e. 27000 ppm, the brine solution was prepared by dissolving analar NaCl in distill in distilled water was being used as the single phase. Different water concentrations of water in oil were used as following: 15%, 25%, 35% and 45%. The solution was saturated by CO2 with pH = 5 and *p*CO2 = 0.54 bar. The experimental conditions are summarized in Table (3).

2.3.2 Inhibitor addition

The Aromatic compounds are chosen in this work to be good a corrosion inhibitor for CO2 corrosion [5, 9, 10]. This compounds were imported from " Akzo Nobel Surfactants company, Stenungsund ,Sweden " .

Aromatic compounds – adsorb onto the steel surface by sharing π-electron density from the aromatic ring with the metal surface. This binding can possibly decrease corrosion rates or change the steel-oil interfacial tension. The aromatic chosen for this study is tetrahydronaphthalene in different concentration 0.05%, 0.1%, 0.2%, 0.5% and 1%.

Table (3). Experimental conditions and measurements.

Total Pressure	1 bar
*p*CO**2**	0.54 bar
Temperature	25 ± 2 °C
Water conc. in oil	15%, 25%,35% and 45%
pH	5 ± 0.05
Material	X65 steel
Inhibitor	Aromatic (1,2,3,4-Tetrahydronaphthalene) $C_{10}H_{12}$ (Molecular weight g·mol^{-1} = 132.2)
Inhibitor concentrations	(0.05, 0.1, 0.2, 0.5 and 1) %

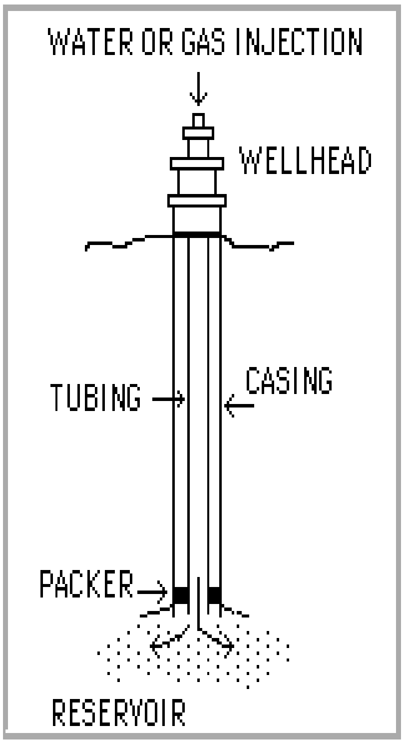

Figure (1). A sketch of a typical oil field gathering system.

2.3.3 Inhibitor Efficiency (λ)

The inhibition efficiency (λ) as calculated according to the following equation [1]:

$$(\lambda) = [(Wu - Wi) / Wu] \times 100 \quad (1)$$

Where:

Wu = weight loss of metal in unhibited solution.

Wi = weight loss of metal in inhibited solution.

2.4 Weight loss technique

The glass cell (beaker) was filled with 250 mL of tested solution that was purged with CO_2 during 2 hrs prior the immersion of the metal coupons. After 2 hrs the oxygen concentration was measured to be less than 10 ppb and the pH was constant (5 ± 0.5) meaning that the system was in equilibrium and saturated with CO_2. The pH of the test solution was adjusted to the desired pH by adding deoxygenated hydrochloric acid solution (HCl). It is important to point out that the CO_2 injection was maintained during the test with the aim of avoiding any oxygen contamination. The cleaned specimens were weighed and exposed to the tested solution. Only one specimen was suspended in each beaker. Test duration was 24 hrs.

After each test, specimens were visually observed. At the end of the experiment, the specimens were final cleaning with brush to remove the corrosion products, immersed in 5% HCl containing hexamine, washed by tap water, rinsed with distilled water, then left to dry and accurately weighed to the 4th decimal of gram. A digital balance with 4 decimal points was used weight the specimens,(type Sartorius BL 2105 Max. 210g, d= 1mg, Germany). The mean value of the weight loss in milligrams was calculated for three test specimens. .

3. Results and discussions

3.1 Effect of water content

The effect of water content in oil solution was studied for the percentages (15%, 25%, 35% and 45%). The carbon steel was found to corrode in the tested solution as shown in Figures (2-4). This was evidenced by the decrease in the original weight of the specimens as the water percent increased. Depending on the water content in oil, the weight loss increase in order:

45% (H_2O) > 35 % (H_2O> 25% (H_2O) > 15% (H_2O)

These findings were in agreement with results in works [1, 5]. The increase in weight loss at high water concentration can attribute to mass transfer rate leading to more water bubbles colliding with the metal surface [7]. The water slugs in oil flow pattern appear at high ratios of water in oil (35% and 45%). The slugs of water make good contact with the metal surface. Hence the system is controlled by oxygen diffusion rate.

3.2 Effect of inhibitor concentration

It was observed from Figures (2-4) that, in all cases studied the extent of weight loss decreased with increase in the concentration of the inhibitor. However, the extent of inhibition did not increase in proportion to the increase in the water content in oil, i.e. the inhibitor works relatively more efficiently in dilute solutions of 35% water content in oil. At an inhibitor concentration of 0.05%, the weight loss was 216 mg, whereas when the inhibitor concentration increased to 1%, the weight loss became 102 mg in the same solution as shown in Tables (4-6).

According to [1, 10] the inhibitors are believed to be generally molecularly absorbed on the active centers of the metal surface. Thus an absorbed layer characterized by a high electrical resistance is formed on the metal surface which may also be responsible for the reduction in the rate of diffusion of ions necessary for the corrosion process. In the present case also, the percentage inhibition vs. inhibitor concentration Figures (2-4) resemble absorption and therefore, confirm the theory that, an absorption phenomenon is occurring on the metal surface.

3.3 Inhibitor efficiency

When the extent of inhibition was examined at different concentrations (0.05-1%) in different water content in oil, it was observed that , the extent of inhibition decreased with increase in the concentration of the water content in oil at a fixed inhibitors concentration of all conditions were used. The inhibitive efficiencies of various concentrations of inhibitors Figures(5-7) increased in the order:

At 45% H_2O: 61.2 at 1% Aromatic compounds,56.8 at 0.5% Aromatic compounds, 53.7 at 0.2% Aromatic compounds ,48.2% at 0.1% Aromatic compounds and 47.3% at 0.05% Aromatic compounds.

The lowest inhibitive efficiency (72%) was obtained with 0.1% concentration whereas the highest efficiency (86%) was achieved at 1% concentration in solution, containing 45% water in oil. Tables (7-9) showed the inhibitor efficiency results of API 5L X65 carbon steel (as received and after heat treatment) in oilfield solution, containing different water content: X1-15% X 2-25% X3- 35% X4-45% with different inhibitor concentrations (Y).

The decrease in inhibitive efficiency with increase in H_2O content in oil may be attributed to the high rate of evolution of hydrogen in concentrated solution which may interfere with the absorption of the inhibitor on the metal surface [9, 10]. Further, it is interesting to note that, in the case of annealing microstructure the inhibition efficiency remains almost at values about (80.6-84.8%) at all water content with concentrations of inhibitors equal 1%. This may be due to better absorptivity of annealing structure in comparison to other structures.

3.4 Effect of heat treatment

The corrosion behavior of used steel was very dependent on the heat treatment. In order to assess the affectivity of different heat treatment, experiments were carried out at annealing and quenching and tempering samples. It was observed that in all cases the extent of inhibition decreased with a rise in water content in oil. The effect being more prominent in the case of annealing, followed by the received condition and then the samples which quenching + tempering. However in the case of quenching + tempering the decrease was not so perceptible.

At constant water content the inhibitive efficiency of Aromatic compounds increases with increase in the concentration of the inhibitor, whereas at constant inhibitor concentration, the efficiency decreases with increase in the water content in oil.

Annealing condition appears to be good microstructure to decrease weight when an Aromatic compound was used. For this microstructure, the weight loss decreased from 284 mg without inhibitor addition in 45% water content in oil to 22mg when 1% Aromatic compounds added to solution, containing 45% $H2O$ in oil, whereas the inhibitor efficiency reached to 84.8% in solution of 45% $H2O$ in oil when inhibitor concentration was 1%. Annealing samples reveal better corrosion resistance compared to Q+T samples (as shown in Tables (7-9)). Works [9, 10] analyzed the structure of corrosion scales. They described two types of scales. The primary scale, formed directly on the corroding surface, which is non-compact, porous, with layer crystals and well adhered. Secondary scale, which can be formed on the top of the primary scale due to the recrystallization on iron carbonate. The secondary scale is compact: non-porous & detaches easily. It was concluded that the corrosion products thickness as well as the adherence to the metal surface depend on the microstructure of the specimen. The primary iron carbonate scales formed on normalized samples were thicker, less porous, more tenacious, better adhered than those formed on the samples, which had (Q+T) ones. Moreover, the crystals forming the scale on normalized steel specimens were found to be larger & more densely packed than those for the (Q+T) specimens. The secondary scale has the same characteristics for both types of microstructures.

The combination of annealing heat treatment of samples and using Aromatic compounds inhibitor offered a better corrosion resistance than the combination of (Q+T) samples.

Annealed samples have better corrosion resistance than the Q+T samples ones. In annealing condition, the corrosion rate was further decreased as inhibitor content increased. In Q+T heat treatment. The corrosion rate was higher than that in annealing condition. The difference in corrosion rate is assigned to the different precipeted phases and their shape & distribution resulting from different heat treatment. The corrosion rate decreases as the ferrite increase as shown in condition of steel as received which contain ferrite more than those in (Q+T) condition of steel.

The microstructure of used steel (as received) presented a weight loss equal to 38 mg in solution containing 15% water and 1% Aromatic compounds in oil solution. These values were higher than that values for the microstructure in the annealed condition in which weight loss equal to 22 mg in the same condition for steel as received. Even more, for (Q+T) microstructure of steel, weight loss was 102 mg in solution contained 35% $H2O$ and 1%

Aromatic compounds in oil solution, while in solution contained 15% H_2O an 1% Aromatic compounds, the weight loss was 115 mg. It is necessary to note that, the inhibition action due to combination of (Q+T) and using Aromatic compounds as inhibitor had independent relationships.

The adherence of the corrosion product film was higher in the quenched samples and they were stiff & tough. The annealed samples surface contained large carbides in the corrosion product therefore; the corrosion rates in this condition were lower than those of Q+T samples. However, the Q+T lead to a decrease in corrosion rate. No protective film was formed on the F/P.

Figures (1-3) showed the relationship between Inhibitor concentration and weight loss of specimens. The inhibitor dosage had been increased from 0.05% to 1%. It should be noted that the weight loss was reduced as inhibitor concentration increased for all conditions of specimens whether, there were heat treated or not. These results are attributed to increase the resistivity of solution and decrease the contact between the metal and the aqueous solution [1, 7, 8].

By comparing Figures (1-3) it can be seen that the presence of inhibitor improves the corrosion resistance for annealed samples. For fully annealing, the weight loss was 5 times lesser than that for (Q+T) samples, while the weight loss of steel (as received condition) was 3 times lesser than that for (Q+T) samples.

These results could be attributed to the microstructures as shown in Figure (8), when the samples had annealed ferrite & pearlite were precipeted while for quenching and tempering samples of temper martensite phase would precipeted [9].The structure of annealed steel served to show the difference between the phase and constituent concepts. In Figure (8 B) , two basic types of structures were clearly evident: the white areas are ferrite and the dark (black) areas are pearlite. The constituents of these specimens are, accordingly, pearlite and ferrite.

Steels that have undergone a simple hardening quench are usually mixtures of austenite and martensite, with the latter constituent predominating. Both of these structures are unstable and slowly decompose, at least in part, if left at room temperature: the retained austenite transforms to martensite. A structure, which is almost completely martensite is extremely brittle and is also very liable to develop quench cracks if aged at room temperature, therefore steels with a simple martensitic structure are of little useful value, and a simple heat treatment called tempering is almost used to improve the properties of quenching steels. In this treatment, the temperature of steel is raised to 430 °C in vacuum furnace, held there for a fixed 2 hours, after which the steel slowly cooled down to room temperature. The obvious intent of tempering is to allow diffusion processes time to produce both a dimensionally more stable structure and one that is inherently less brittle.

They also observed differences in the inhibitor efficiency Figures (4-6) that were attributed to variations in the microstructure in the steel Figures (7 and 8).The inhibitor efficiency increased with an increase in the inhibitor concentration for all microstructures.

In the case of CO_2 corrosion the anodic a cathodic reactions are the oxidation of iron and the reduction of hydrogen, respectively [6]. If it is considered that the active sites on the metal surface are the same for both reactions before adding the inhibitor. When the inhibitor is present because its adsorption change those active sites and therefore the anodic and cathodic reaction rates. Another important aspect is that the change in inhibitor concentration is proportional to the inhibitor efficiency Figure (3) , Table (2). Higher efficiencies were observed when the change in inhibitor concentration was toward more values.

Works [5, 10] reported similar results. They attributed the loss of inhibition efficiency, with the inhibitor concentration, to the tendency of inhibitor molecules to repel each other. When the inhibitor concentration was greater than 10 ppm, the inhibitor molecules tended to perpendicularly adsorb on the metal surface due to a repellent function [1,6]. As a consequence, instead of adsorbing paralleled to the metal surface, decreasing the active sites, the inhibitor molecules would cover a smaller metal surface area, which resulted in a less corrosion efficiency.

The adsorption of inhibitors on the metal surface has been studied recently by [7] by molecular modeling. The inhibitor molecules had larger adsorption energy than the water molecule. This means that the inhibitor molecules adsorb preferentially on the metal surface in aqueous medium, justifying the rapid decrease weight loss when the inhibitor is added.

4. Conclusions

1- Weight loss increases as water content in oil solution increases in order:

45% (H_2O) > 35 % (H_2O> 25% (H_2O) > 15% (H_2O)

2- In all cases studied the extent of weight loss decreased with increase in the concentration of the inhibitor but the extent of inhibition did not increase in proportion to the increase in the water content in oil, i.e. the inhibitor works relatively more efficiently in dilute solutions of 35% water content in oil. .

3- The inhibitive efficiencies of various concentrations of inhibitors increased in the order:

At 45% H_2O: 61.2 at 1% Aromatic compounds,56.8 at 0.5% Aromatic compounds, 53.7 at 0.2% Aromatic compounds ,48.2% at 0.1% Aromatic compounds and 47.3% at 0.05% Aromatic compounds.

4- The corrosion behavior of used steel was very dependent on the heat treatment. The effect being more prominent in the case of annealing, followed by the received condition and then the samples which quenching + tempering.

5- The combination of annealing heat treatment of samples and using Aromatic compounds inhibitor offered a better corrosion resistance than the combination of (Q+T) samples.

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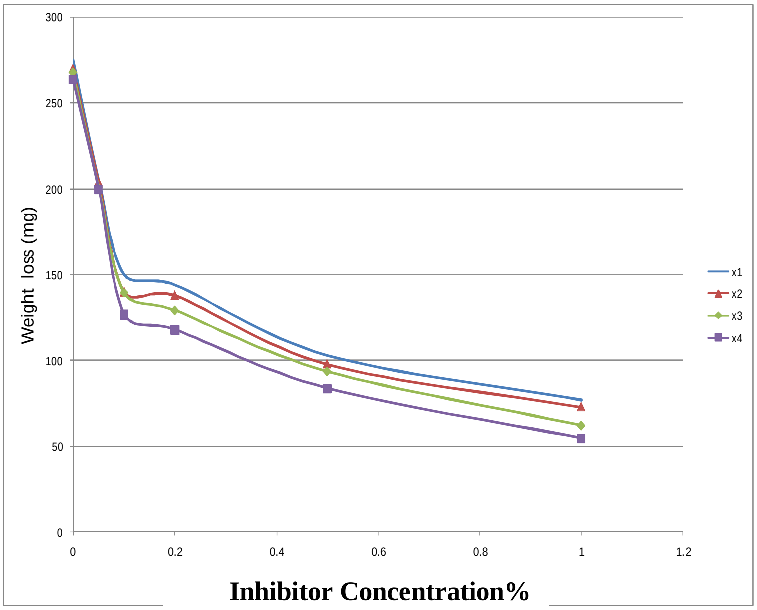

Figure (2). Variation of weight loss with different inhibitor concentrations for API 5L X65 carbon steel (as received) in oilfield solution, containing different water content: 1-15% 2-25% 3- 35% 4-45%.

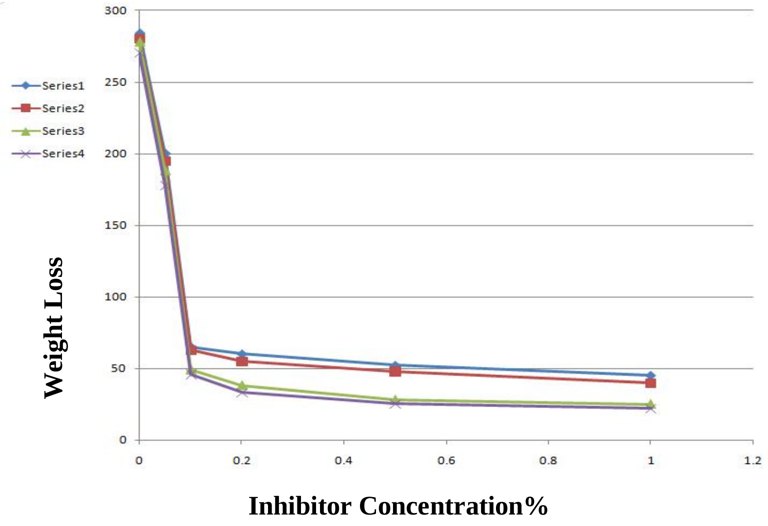

Figure (3). Variation of weight loss with different inhibitor concentrations for API 5L X65 carbon steel (after annealing) in oilfield solution, containing different water content: 1-15% 2-25% 3- 35% 4-45%.

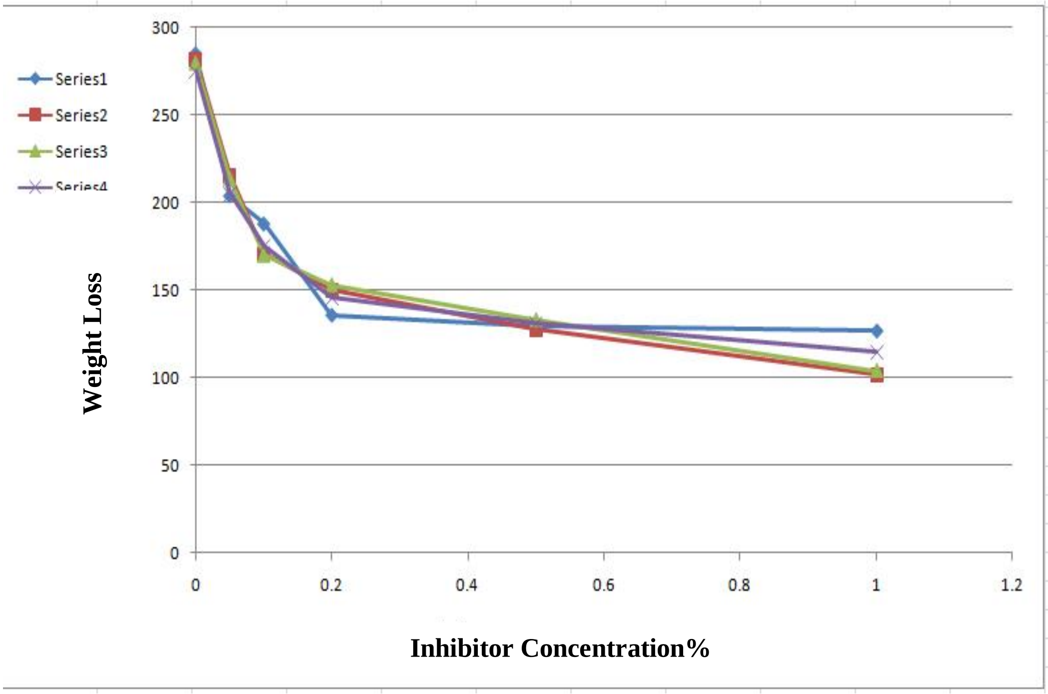

Figure (4). Variation of weight loss with different inhibitor concentrations for API 5L X65 carbon steel (after quenching + tempering) in oilfield solution, containing different water content: 1-15% 2-25% 3- 35%4-45%45%.

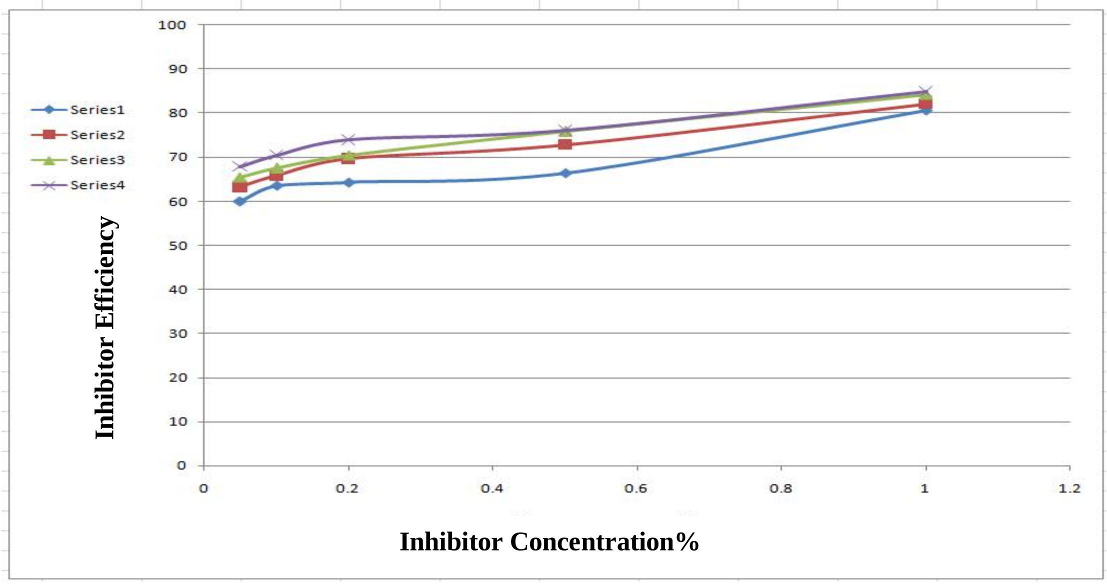

Figure (5). Effect of concentration of Aromatic compounds on their efficiency as inhibitors for API 5L X65 carbon steel (after annealing) in oilfield solution, containing different water content: 1-15% 2-25% 3- 35% 4-45%.

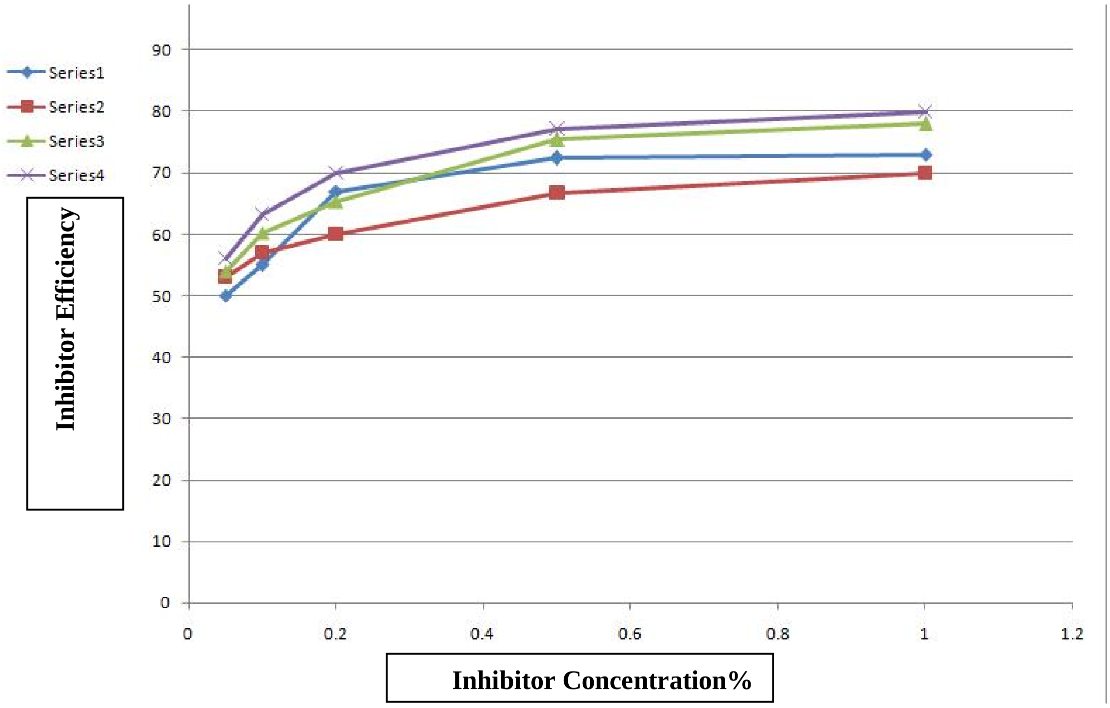

Figure (6). Effect of concentration of Aromatic compounds on their efficiency as inhibitors for API 5L X65 carbon steel (as received) in oilfield solution, containing different water content: 1-15% 2-25% 3- 35% 4-45%.

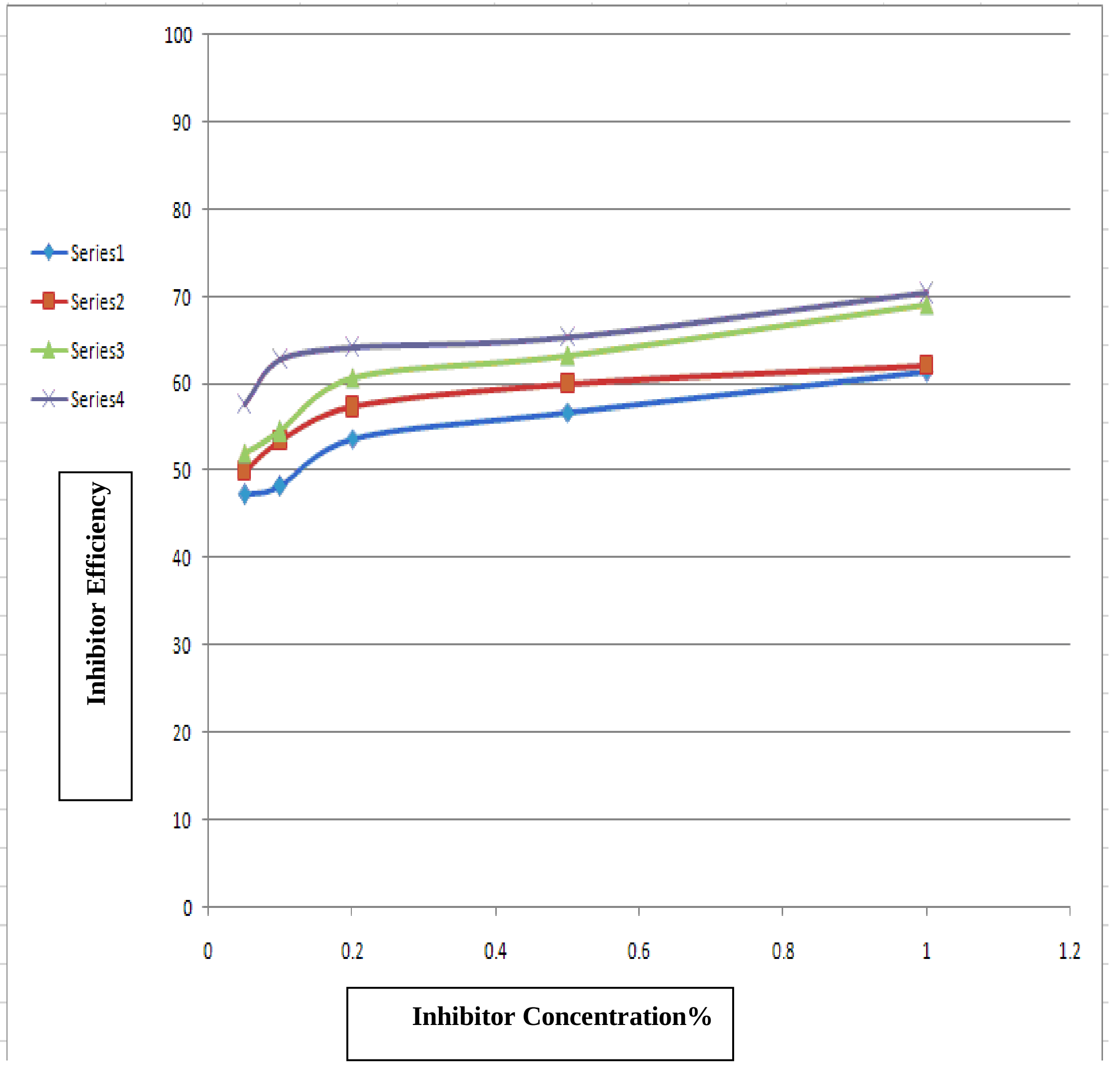

Figure (7). Effect of concentration of Aromatic compounds on their efficiency as inhibitors for API 5L X65 carbon steel (after quenching + tempering) in oilfield solution, containing different water content: 1-15% 2-25% 3- 35% 4-45%

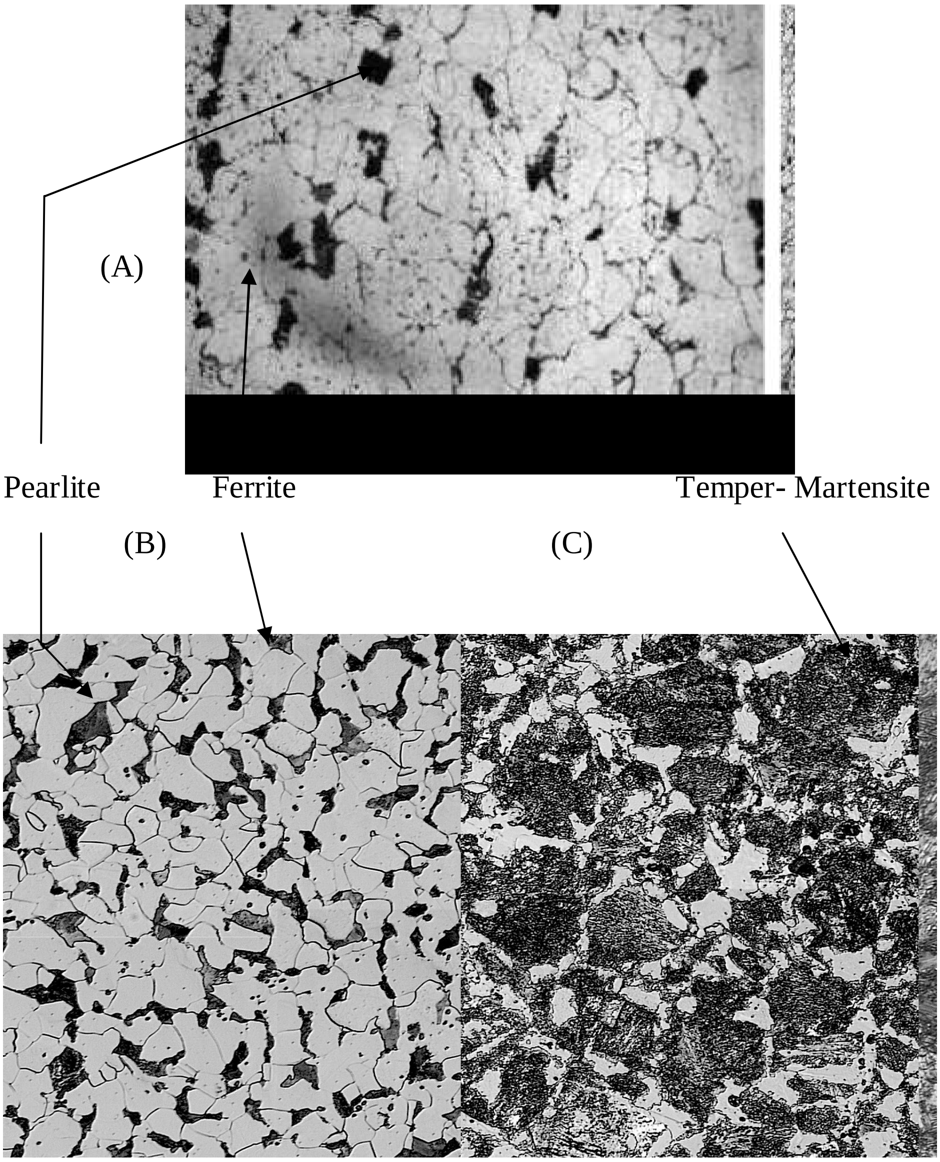

Figure (8). Optical micrographs of API 5L X65 carbon steel samples:{Approximately 250X}.

(A) as received (B) after annealing. (C) after quenching + tempering.

Table (4). The weight loss results of API 5L X65 carbon steel (as received) in oilfield solution, containing different water content: X1-15% X 2-25% X3- 35% X4-45% with different inhibitor concentrations (Y).

Inhibitor Concentration (Y)	Weight Loss, mg.			
	X1	X2	X3	X4
Nil	242	266	279	282
0.05	195	200	212	218
0.1	112	124	168	175
0.2	103	135	140	143
0.5	51	63	85	96
1.0	38	48	55	60

Table (5). the weight loss results of API 5L X65 carbon steel (After annealing) in oilfield solution, containing different water content: X1-15% X 2-25% X3- 35% X4-45% with different inhibitor concentrations (Y).

Inhibitor Concentration (Y)	Weight Loss, mg.			
	X1	X2	X3	X4
Nil	270	278	280	284
0.05	178	188	195	200
0.1	46	49	63	65
0.2	33	38	55	60
0.5	25	28	48	52
1.0	22	25	40	45

Table (6). The weight loss results of API 5L X65 carbon steel (After Quenching + Tempering) in oilfield solution, containing different water content: X1-15% X 2-25% X3- 35% X4-45% with different inhibitor concentrations (Y).

Inhibitor Concentration (Y)	Weight Loss, mg.			
	X1	X2	X3	X4
Nil	275	280	282	285
0.05	205	214	216	204
0.1	175	170	171	188
0.2	146	153	150	136
0.5	131	133	128	130
1.0	115	104	102	127

Table (7). The inhibitor efficiency results of API 5L X65 carbon steel(after annealing)) in oilfield solution, containing different water content:15% X1-X 2-25% X3-35%X4-45% with different inhibitor concentrations(Y).

Inhibitor Concentration (Y)	Weight Loss, mg.			
	X1	X2	X3	X4
0.05	67.8	65.4	63.2	60
0.1	75.0	67.5	65.8	63.5
0.2	73.9	70.5	69.6	64.5
0.5	76	75.8	72.8	66.4
1.0	84.8	84.2	82.1	80.6

Table (8). The inhibitor efficiency results of API 5L X65 carbon steel (as received) in oilfield solution, containing different water content: X1-15% X 2-25% X3- 35% X4-45% with different inhibitor concentrations Y).

Inhibitor Concentration (Y)	Weight Loss, mg.			
	X1	X2	X3	X4
0.05	56	54	53	50
0.1	63.1	60.3	57	55
0.2	70	65.1	60	67
0.5	77.2	745.	66.7	72.3
1.0	80	78.	70	73

Table (9). The inhibitor efficiency results of API 5L X65 carbon steel (After Quenching + Tempering) in oilfield solution, containing different water content: X1-15% X2- 25% X3- 35% X4-45% with different inhibitor concentrations (Y).

Inhibitor Concentration (Y)	Weight Loss, mg.			
	X1	X2	X3	X4
0.05	57.7	52	50	47.3
0.1	62.8	54.5	53.4	48.2
0.2	64.2	60.7	57.3	53.7
0.5	65.3	63.3	60.0	56.8
1.0	70.4	69.1	62.1	61.2