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EVALUATION OF INHIBITOR EFFICIENCY IN CRUDE OIL PIPELINE OF MISSAN OIL FIELDS SOUTH IRAQ

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Abstract: In this paper, three different types of pipeline materials and four types of corrosion inhibitors were test using immersion method in the crude oil solutions collected from six fields southern Iraq. The influence of crude oil composition; temperatures and pipeline roughness were performed. As a result the X80 carbon steel has lower corrosion rate, while ductile iron has largest value and X60 steel shows moderate value. Imidazonline inhibitor has best efficiency while Great inhibitor shows lower efficiency, the pipeline and oil-line inhibitor show moderate values. Increasing roughness of pipeline material reduced inhibitor adsorption and lead to increase of corrosion rate.

Keywords: *crude oil, immersion test, inhibitor, adsorption, roughness*

تقييم كفاءة مثبطات التأكل في خطوط أنابيب النفط الخام لحقول نفط ميسان جنوب العراق

الخلاصة: في هذا البحث، ثلاثة أنواع مختلفة من مواد خطوط الأنابيب وأربعة أنواع من مثبطات التآكل تم اختبارها باستخدام طريقة الغمر في محليل النفط الخام التي تم جمعها من ستة حقول مختلفة من جنوب العراق. تأثير تركيب النفط الخام، درجات الحرارة وخشونة سطح الانابيب تم تقيمها. بينت النتائج ان الصلب الكربون X80 يمتلك اقل قيم من معدلات التآكل ، في حين ان الحديد المطاوع يمتلك أكبر قيمة بينما اظهر الصلب الكربوني X60 قيمة متوسطة . مثبطات التأكل من نوع Imidazonline تمتلك أفضل كفاءة في حين يظهر المثبط Great inhibitor أقل كفاءة، بينما المثبطات pipeline inhibitor و oil-line inhibitor اظهرا قيم متوسطة. زيادة خشونة سطوح الانابيب يقلل الامتزاز للمثبط وهذا يؤدي إلى زيادة معدل التآكل.

1. Introduction

Oil pipelines transport liquid petroleum products from one point to another. There are generally three types of oil pipelines: first, gathering lines, used for transporting oil in short distances and the pipes diameter range from 10.2 to 30.2 cm.

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Feeder lines used to transport the oil product from oil storage tanks or processing plants to the Transmission pipelines and this type generally bigger than gathering lines. Third, transmission lines can be up to 122 cm in diameter and transport crude oil from producing to export or consume areas [1].

Corrosion in crude oil pipelines is one of the major problems closely associated with the presence of water and contaminant including chlorides, sulfates, CO_2 and H_2S dissolved gases. One way for protecting the internal oil pipelines against corrosion by using corrosion inhibitors. An inhibitor is a substance when added in small concentrations decreases the effective corrosion rate. Inhibitors fall into four general categories based on mechanism and composition. These categories are barrier layer formation, neutralizing, scavenging, and environmental modification. A number of factors may influence inhibition petroleum pipelines such as temperature and water chemistry [2].

Miksic et *al.* [3] evaluated several types of corrosion inhibitors in electrolyte/hydrocarbon mixture. They show the corrosion inhibitors are effective in the flow rates of mixtures. Shawki [4] analysis of two failure cases of corrosion in oil pipeline, the first case represents a core pipeline corrosion in deep well and the second case was diagnosed of wrong construction design of above ground pipeline. Sivokon et *al.* [5] discussed typical corrosion and inhibitor protection conditions in oilfield pipelines of the west Siberia region and existing approaches to the laboratory simulation of corrosion situations in oilfield pipelines. They compared the simulation conditions and capabilities of laboratory test methods. Safri et *al.* [6] study the corrosion problems of crude oil pipeline of Kuwait that transport crude oil from Wafra oil field located south Kuwait to Mina of Kuwait to export. They show that half pipeline severe from corrosion and need repairs. Yadav et *al.* [7] used three synthesized Imidazole derivative Methoxyphenyl, 1-phenyl and Chlorophenyl methyl-H-Imidazole as corrosion inhibitor for N80 steel in 15 % HCl solution. They show that all corrosion inhibitor take place through absorption phenomena. Kusmono [8] study and analyze the failure of a subsea crude oil API 5L X52 steel pipeline. He suggested that the cause of failure is electrochemical corrosion combined with mechanical process. Wang *et al*. [9] discussed the performance of corrosion inhibitor in crude oil production conditions. They show that the addition of corrosion inhibitors into oil-brine mixed fluids may reduce the corrosion of pipelines. Michael et al [10] studied the effect of temperature on the ability of imidazoline as a corrosion inhibitor in crude oil transporting. They showed that the pipeline conditions and imidazoline molecular structure are needed in order to affirm the optimal applicability of imidazoline as a corrosion inhibitor.

The aim of this research is the studying of corrosion phenomena in crude oil transmission pipelines from Missan oil fields to a storage tanks at Al-Fao city south Iraq using immersion corrosion test method. Four different types of corrosion inhibitors was test, evaluated and explained their results. Various conditions that effect on corrosion includes: temperature, adsorption of inhibitors and surface roughness of materials were evaluated also.

2. Experimental Analysis

2.1 Pipeline Material and Specimen Preparation

In Iraq, there is about 300 km of network pipelines have three different size elongated from Missan oil fields to the storage tanks in Al-Fao city of Basrah proven. Old pipelines of ductile iron materials have 35.56 cm nominal size diameter, class 300 and wall thickness 7.62 mm. New lines of API 5L X60 and API 5L X80 seamless carbon steel which have a diameter of 71.12 cm and 108. 4 cm respectively.

The wall thickness is 14 mm. The pipelines have a maximum allowable operating pressure of 50 bars. The API of the crude oil in the range of 22 to 28 [11]. The chemical compositions of the metals tested are listed in the References. [12, 13 and14]. Tables 1 to 3 show lists of elements composition of the metals measured experimentally using spectrophotometer equipment.

Table 1. The Chemical Composition of API 5L X80 Carbon Steel measured experimentally.

Metals	%	Metals	%
C	0.08	Al	0.035
Si	0.24	Mo	0.31
Mn	1.65	Ni	0.18
P	0.014	Nb	0.06
S	0.0005	Fe	Balance

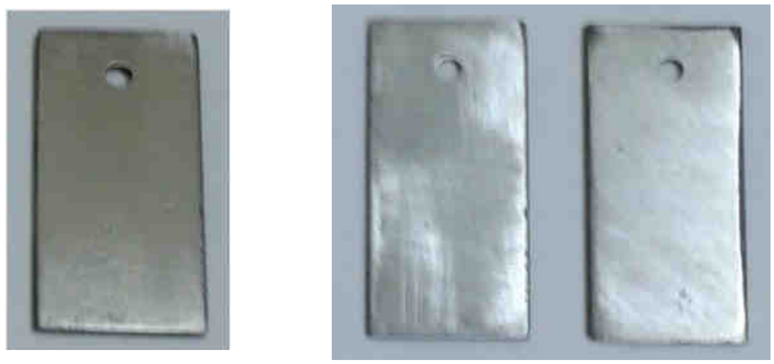
Table 2. The Chemical Composition of X60 Carbon Steel measured experimentally.

Metals	%	Metal	%
C	0.008	Al	0.01
Si	0.25	Cu	0.01
Mn	1.51	Ti	0.02
P	0.01	V	0.06
S	0.004	Nb	0.05
Cr	0.01	N	0.008
Ni	0.01	Mo	0.256

Table 3. Chemical Composition of Ductile Iron measured experimentally.

Metal	C	Si	P
%	2.8.	2.3	0.07

The specimens were cut from plate pipe in rectangular dimension (50cm * 20cm) and have thickness of 5mm. Suspension holes were drilled through each specimen. The specimens have been polished using sandpaper (160, 180, and 200 grades), then washed by distilled water and dried by hot air at atmospheric pressure and temperature. The specimens are shown in Fig.1.



A B C

Figure 1: Specimens for A-Ductile Iron B- X60 Carbon Steel C- X80 Carbon Steel

2.2 Crude Oil Samples Analysis

The crude oil samples were collected from the six oil fields located in Missan proven southern Iraq. The crude oil material compositions, physical properties and dissolved gases are analyzed in Nahr Umer laboratory of south oil company and summarized in Table 4 and Table 5. The original pH of crude oil as average value about 5 as recorded from various crude oil fields.

Table 4. Material Composition of Different Crude Oil..

Materials	Fields					
	Noor	Bazerkan	Faqa1	Faqa2	Halfaya	Abu-Garab
Iron ppm wt	1.1	2.2	3.76	3.9	2.8	1.77
Copper ppm wt	6.1	3	5.1	5.2	3.6	1.3
Vanadium ppm wt	30	32	31	31	34	29
Nickel ppm wt	8.7	10	11	11.6	7.1	11
Cadmium ppm	0.78	0.41	0.52	0.64	0.23	0.8
Aluminum ppm wt	0.44	0.13	0.31	0.33	0.16	0.27
Manganese ppm wt	0.30	0.17	0.22	0.22	0.27	0.10

Table 5. Physical Properties of Crude Oils.

Properties	Fields					
	Noor	Bazergan	Faqa1	Faqa2	Halfaya	Abu -Gharab
API	26	24.7	22.5	23.2	27	25
Sulfur %	4.6	5.12	3.89	3.9	4.85	4.86
Water content %	2.4	2	1.96	2.05	1.85	2.3
Salt NaCl ppm	31.5	44	24.4	22.3	14	11
Asphaltenes %	15.8	13.2	13.5	12.6	10.1	14.8
Specific gravity at 20^{o}C	0.879	0.890	0.905	0.884	0.913	0.858
Kinematics viscosity cst at 20^{o}C	40.1	45	33.5	33.6	44	39
Dielectric constant	2.52	1.78	2.11	2.02	1.92	1.97
H_2S (g) ppm	0.32	0.21	0.42	0.40	0.49	0.45
CO_2 (g) ppm	0.96	0.41	0.67	0.77	0.57	0.83

2.3 Corrosion Inhibitors

In oil and gas industry, majority of modern corrosion inhibitors use nitrogen-containing compounds. Various amines (primary, secondary and tertiary both aliphatic and heterocyclic) from pyridines and Imidazoline class, their salts, amine alcohols and Triazines are applied as corrosion inhibitors [15]. In Iraq crude oil transitions pipelines, a large number of corrosion inhibitors have been used. Table 6 shows the commercially corrosion inhibitors and company manufactures which uses in the last years. The great inhibitor is referred as model A, pipeline inhibitor model B, Imidazonline inhibitor model C, and oil line inhibitor (IOCT-3250) is model D. The quantity of four inhibitors added per litter for testing at the concentration about of 100 ppm in the crude oil solutions.

Table 6. Corrosion Inhibitors Types and Manufacturing Company.

Models	Corrosion Inhibitor Name	Company Manufacturing
A	Great corrosion inhibitor for crude oil pipeline	Zhengzhou Top Trading Co., Ltd., China
B	Pipeline corrosion inhibitor	The Zoranoc Oilfiled Chemical, China
C	Imidazonline corrosion inhibitor	Zhengzhou Top Trading Co., Ltd., China
D	Oil line corrosion inhibitor (IOCT-3250)	Imperial Oilfield Chemicals Pvt. Ltd., Baroda, india

3. Immersion Test Method

Fig. 2 shows three water baths which were used for immersion testing and a four-digit weighing balance used to determine the weight difference of each coupon before and after the immersion test. After taking the initial weight and dimensions of each coupon, the coupons are suspended inside the 500 ml glass beaker using the nylon thread and long pin, and then the beakers is filled with the test crude oil solutions and putting in water baths. The glass beaker is filled with 500 ml of crude oil solution and then adding the four types of inhibitors at concentration of 50 ppm of each type for each type of crude oil solutions. The test temperature applied in range of 30ºC to 65ºC. The specimens are withdrawn from the immersion crude oil solution, in a set period of different time duration 15 day and for a total 180 days at the set temperatures. Then the specimens washed with kerosene to remove oil deposits and immersed in the cleaning solution for 1 min to remove the oxidation films. The cleaning solution contains 50 g of sodium hydroxide with 200 g of zinc dust in 1L of pure water [16]. Then the specimens were air-dried at room temperature and weighted. The weight of the cleaned coupon was subtracted from the initial weight to determine the mass loss due to corrosion process. The corrosion rates (C_r) in mm/year are calculated by assuming uniform corrosion over the entire surface of the specimen and given by the following formula [17]:

$$C_r = \frac{W * K}{\rho\, A\, t} \quad (1)$$

Where,
K = 8.76*10^4 for (C_r) in (mm/year),
ρ: Mass density of metal in (kg/m^3),
A: Total surface area of specimen (m^2)
t: Time of immersion in (hr.)

From the corrosion rate, the percentage inhibition efficiency (E_f %) and surface coverage (θ) were calculated using the following equations [18] :

$$E_f\,\% = \frac{C_r - C_{ir}}{C_r} * 100 \qquad (2)$$

$$\theta = \frac{C_r - C_{ir}}{C_r} \qquad (3)$$

Where, C_r and C_{ir} are corrosion rates in the absence and presence of inhibitor respectively.

Water Bath 1 Water Bath 2 Water Bath 3 Weight Balance

Figure 2: Water Baths and Weight Balance

4. Results and Discussion

4.1 Immersion Test using Different Metals and Crude Oils

Figs. 3 to 8 show the corrosion rate (mm/yr) vs. temperature obtained from immersion corrosion test of the three pipelines materials: ductile irons, X60 and X80 carbon steel in the six crude oil solutions for a period of 180 days. The corrosion test is achieved over the range of test temperatures 30^{o}C to 65^{o}C. It can be shown from Fig.3, at low temperature less 45^{o}C, small increase in corrosion rate obtained but after 45^{o}C, the corrosion rate increase by large increament. This attibuted to that, as the crude oil temperature rises, the crude oils begains to degradtions and relase more ions, these ions move more freely through the crude oil and increase oxidation and reduction processes, this lead to faster corrosion rates.

Crude oil contains various impurities such as salts, dissolved gases, materials, …etc., these impurities are affected by temperatures change. As the temperature increases, the generation of corrosion products such as $FeCO_3$, FeS, Fe_3C and other films will increase due to the reaction of CO_2, H_2S and other components in crude oil with metal surface. The chloride ion can easily ingress through the oxide film and may casuses intiation of pits or craks in metal surface. On the other hand temperature effect on solubility of oxygen gas in crude oil solution. The solubility of oxygen decreases with increasing temperatures but the diffusion rate of oxygen increases. An increase in temperature increases the speed at which the oxygen molecules move at and the decrease of the surface tension of the crude oil. An increased speed of the oxygen molecules will yield faster oxygen diffusion rate which tends to accelerate the corrosion process.. The percentage of dissolved CO_2 gas as given in Table 5 is larger that of H_2S in all types of crude oils, so the effect of H_2S dissolved gas in corrosion rate is less compared to CO_2.

Temperatures have effect on the ability of trace elements to react with other components in crude oils or with metal surface. These trace elements can interact with sulfur compounds to form a variety of sulfur-metal salts such as Cu_2S. All crude oil tests have small percent of elements as indicated in Table 4. These elements have small affect in corrosion problems at low temperature but causes severe problems at higher temperatures.

Increasing the temperature effects the various properties of crude oil especially asphalt and dielectric constant. The asphalt has high molecular weight and polar compounds and has higher tendency to be adsorbed on the metal surfaces and form stronger bond with the metal surface. It was observed that as the concentration of asphalt increases, the corrosion rate decreases as shown in Table 5. The dielectric constant of crude oil is within the range (1.78- 2.52) as illustrated in Table 5 which was measured in the laboratory. The dielectric constant of water is about 80 at room temperature, so that different water percentage contents in crude oil will have an effect on the dielectric constant and then in corrosion process.

The density and viscosity of crude oil are two important factors and depends on temperature. A low viscosity leads to an easy separation of water from the crude oil mixture. If the temperature of the crude oil increases, it causes lower its viscosity and shortening the time for water separation from crude oil. Increase the water percent in crude oil leads to increase the oxygen diffusion and oxidation process and therefor the rate of corrosion increases.

If corrosion rate is compared between crude oil of the six fields, it can be seen that the Noor crude oil has the highest corrosion rate, while Halfaya crude oil shows the least values, other crude oil shows moderates values. This may be because it has the highest water percent, lower viscosity and it has high impurities such as salts, metals, dissolved gases ... etc. Table 7 show comparison of corrosion rate obtained at temperature 65^{o}C.

Table 7. Comparisons of corrosion rate mm/y of various pipeline metals and crude oil solutions at 65^{o}C.

Materials	Oil fields					
	Halfaya	Faqa1	Abu Gharab	Faqa2	Bazurkan	Noor
Ductile iron	0.574	0.633	0.706	0.751	0.816	0.967
X60 steel	0.472	0.504	0.622	0.664	0.728	0.844
X80 steel	0.391	0.423	0.545	0.607	0.675	0.736

As indicated from Table 7 the ductile iron have the largest value of corrosion rate, X80 carbon steel have lowest value and X60 carbon steel material show moderate value. This attributed to various factor effect on value of corrosion resistance especially carbon percent contains. As given in tables 1, 2 and 3 the ductile iron material have higher values of carbon percent 3% min. compared to X80 and X60 carbon steel which have a much lower carbon

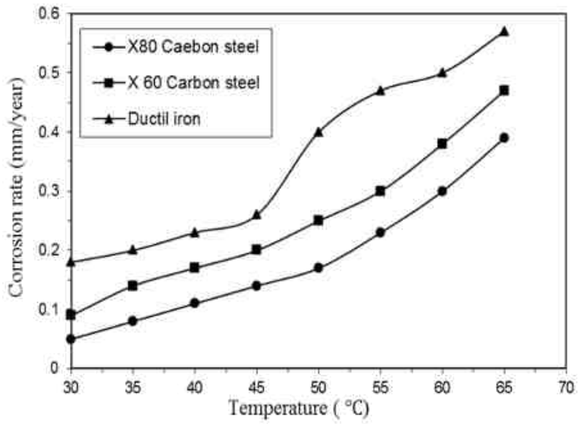


Figure 3: Corrosion rate vs. temperature of the three metals in Halfaya crude oil.

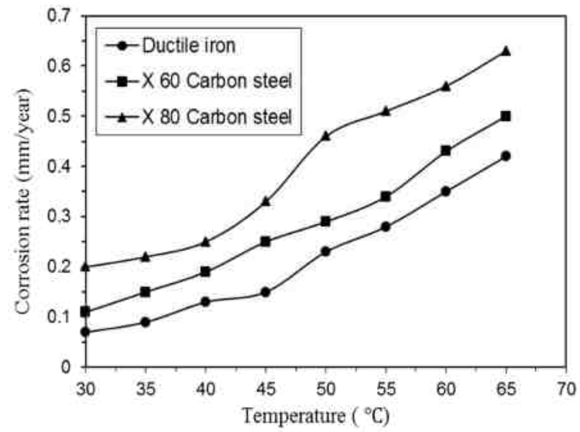


Figure 4: Corrosion rate vs. temperature of the three metals in Faqa 1 crude oil.

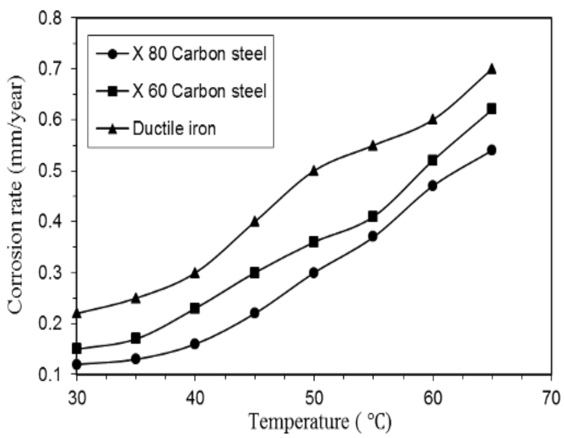


Figure 5: Corrosion rate vs. temperature of the three metals in Abu Gharab crude oil.

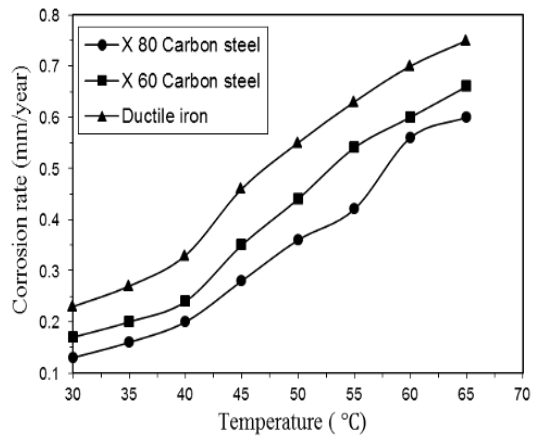


Figure 6: Corrosion rate vs. temperature of the three metals in Faqa 2 crude oil.

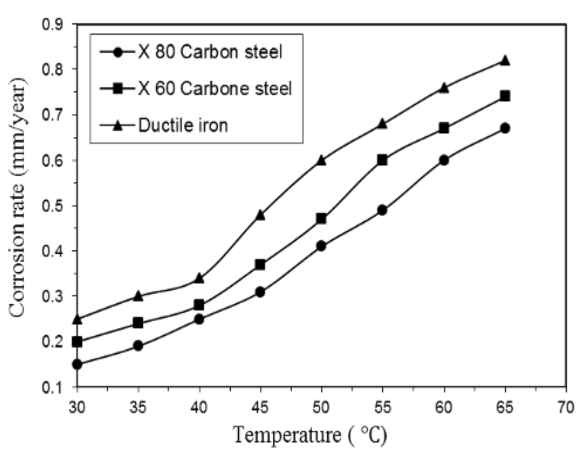


Figure 7: Corrosion rate vs. temperature of the three metals in Bazurkan crude oil.

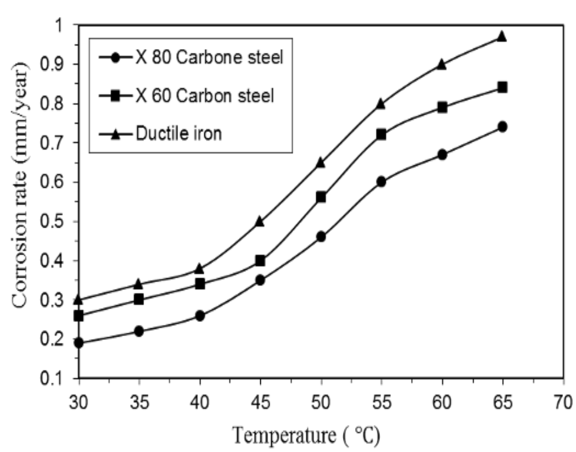


Figure 8: Corrosion rate vs. temperature of the three metals in Noor crude oil.

content and all of the carbon is present in a combined form. Increased carbon means increased brittleness of ductile iron or make it softer compared to other alloys. This make ductile iron affected by corrosion component in crude oil more compared to the tow other alloys.

4.2 Evaluation of Inhibitors

To indicate protection efficiency of inhibitor and the behavior of different pipe material in crude oil solutions with inhibitors, four different types of inhibitors from different companies are tested. Figs. 9 to 14 show the corrosion rates vs. temperatures obtained from the immersion test of the three metals in the six different crude oil solutions with inhibitors for a period of 180 days. As shown, a similar behavior of curves is observed for all meterials after add the inhibitor compared with that case without inhibitor. There is biggest decrements of the corrosion rate values for all materials in all crude oils after 45^{o}C. As shown the model C which contains Imidazoline with fatty acid is the best and gave lower values of corrosion rate, while model A which contain amines with different addives gives high values, other shows moderates values. The efficiencies of corrosion inhibitors of the four models tested were calculated using eq. 2 and the results are shown in Table 8.

Form Table 8, the maximum efficiency obtained is 94.15 % of model C in Faqa1 crude oil and minimum efficiency was 80.97 % of model A in Noor crude oil. The minimum values of corrosion rate obtained from tested X80 steel in Halfay crude oil was 0.027 mm/yr. The maximum value of corrosion rate obtained from test ductile iron in Noor crude oil was 0.205 mm/yr.

Fig. 15 show example of effect of the temperatures in surface coverage adsorption of four types of corrosion inhibitor for the three pipeline materials in Halfay crude oil calculated using eq.3. As indicated the temperatures have more effect of coverage adsorption of corrosion inhibitor. The adsorption decreases with the rise of temperature; these attributed that as a temperature increase, the dissolution of crude oil compositions increase and release ions. These ions are mixed with inhibitor and lead to increase reactions at pipeline metals surface.

The difference in efficiency of various inhibitor tested attributed to the different of the protect mechanism that inhibitor protect the metals surface and then prevent or minimize the corrosion process. Model D which consists from organic compounds, the inhibitors act by competitive adsorption on the metal surface with the aggressive ion and by blocking the active corrosion sites. Model C has Imidazoline which consists from amine-nitrogen with fatty acids has aggregation as a layer on the metal surface for corrosion inhibition [10, 19]. The Imidazolines has a large ability to form cations and these means strongly adsorbed onto the negatively charged surface of metals. The structure formula and adsorption of Imidazolines with fatty acid is representing in figs.16 and.17 respectively. The molecular structure of Imidazolines can be divided into three different sub-structures: head group, hydrocarbon tail group and pendent group. The head and pendent groups promote bonding of the molecules to the metal surface, while; the hydrocarbon tail forms a protective layer having strong attraction to crude oil impurities and water since it contains a polar head group. This, the length of the hydrocarbon tail chain has a key role in the inhibitive behavior of the Imidazolines. After Imidazoline corrosion inhibitor absorbed on the surfaces, the hydrocarbon tail layer becomes in contact with crude oil impurities and other compounds especially the water and as the hydrocarbon tail chain length increases, lead to increased protection efficiency. The increases of hydrocarbon tail chain length leads to increase the thickness of protection layer form and this increased the protection efficiency. On the other hand, the double bond between nitrogen and carbon may broke and increase interaction between inhibitor and metal surface and increasing protection efficiency.

Model A and B contain amine ($-CH_2-NH-CH_2$) with different additives shown in fig.18. Film-forming amines have a strong affinity to metal surfaces, because of free electron pair of amine nitrogen. Amines can form a bond with metal surfaces and the carbon chain in this case outwards. Due to the existence of a large number of amino groups, the bonding to the metal surface takes place at several points and it is therefore quite strong. The carbon chains are directed mostly horizontally or on the metal surface and offer therefore a good protection.

The important factor effects on the inhibitor efficiency are adsorption of inhibitor on metal surface. The adsorption is influenced by the roughness of material, the type of aggressive impurities in crude oil electrolyte (dispersibility) and the chemical structure of inhibitors. In all inhibitors, the molecules have a hydrocarbon chain attached to the polar group, the length of which varies. The adsorption of the corrosion inhibitor from aqueous solution onto the metal surface is driven by both of the polar head group and the hydrocarbon tail group. The adsorbed inhibitors are acted as a waterproof barrier between the corrosive aqueous and steel pipe.

The adsorption of inhibitor on the metal surface is influenced by surface roughness. The three types of metals roughness are measured experimentally using Mitutoyo Surftest SJ-210 surface roughness tester manufactured by DMV, UK. The roughness obtained from tests as average values are: 120, 63 and 42 µm for ductile iron, X60 steel and X80 steel pipe respectively. By comparisons the surface roughness, the X80 steel has lower roughness (smooth surfaces) and large surface coverage by inhibitors, while ductile iron has higher surface roughness and this lead to decrease the surface coverage by inhibitors and X60 show moderate value. Fig.19 show the effect of roughness of materials in surface coverage during test.

One of the most important oil components that affect the spread and the adsorption of corrosion inhibitor in metal surface in crude oil solution is the ratio of asphalt. Asphalt sticks to the surface of the metal, especially the internal lower surface of pipe and prevent adsorption, pool and spread blocker corrosion inhibitor on the metal surface, leading to a decline in the efficiency of corrosion inhibitor. Note from table 5 that the percentage of asphalt in the Halfaya oil field is 10.1 % while at the Noor field is 15.8 %, this value is higher than all other types of crude oils. Raising the temperatures leads to the disintegration of asphalt and mixing with corrosion inhibitor and penetration of water to the surface of the metal and this in turn increases the corrosion rates.

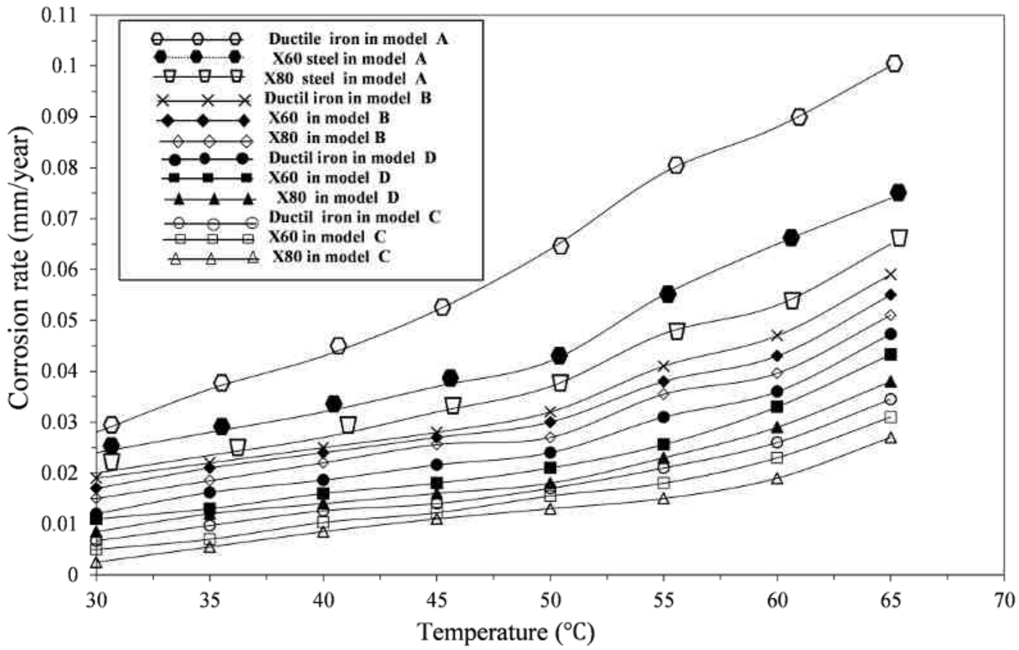


Figure 9: Corrosion rate vs. temperature obtained from immersion test of different inhibitor and materials for Halfaya crude oil.

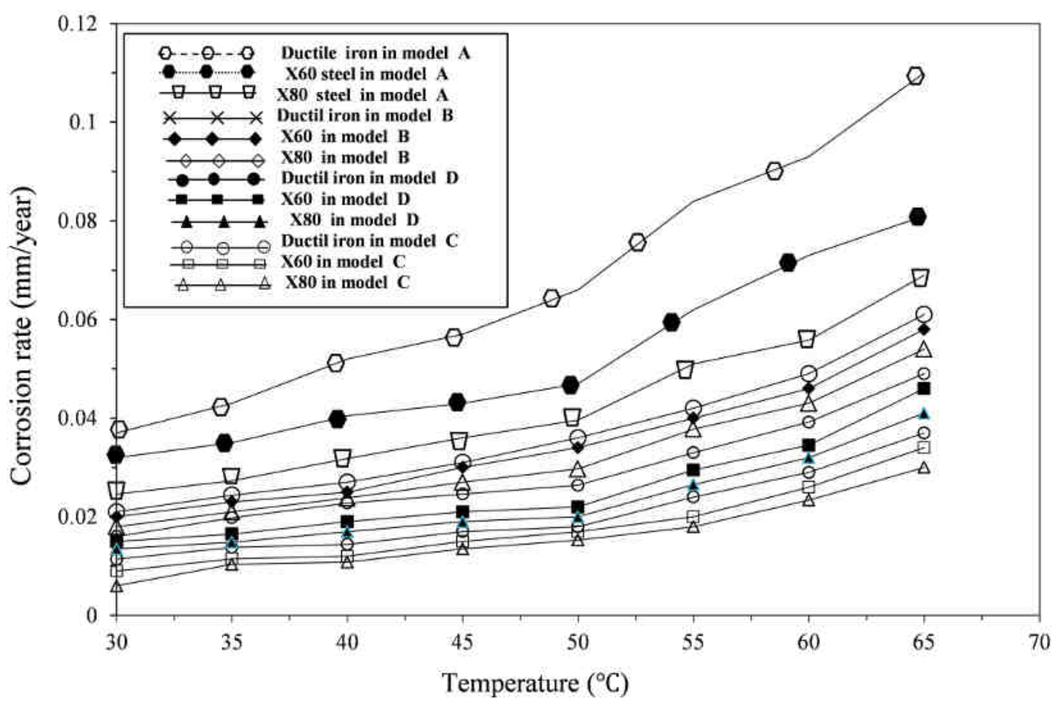


Figure 10: Corrosion rate vs. temperature obtained from immersion test of different inhibitor and materials for Faqa1 crude oil.

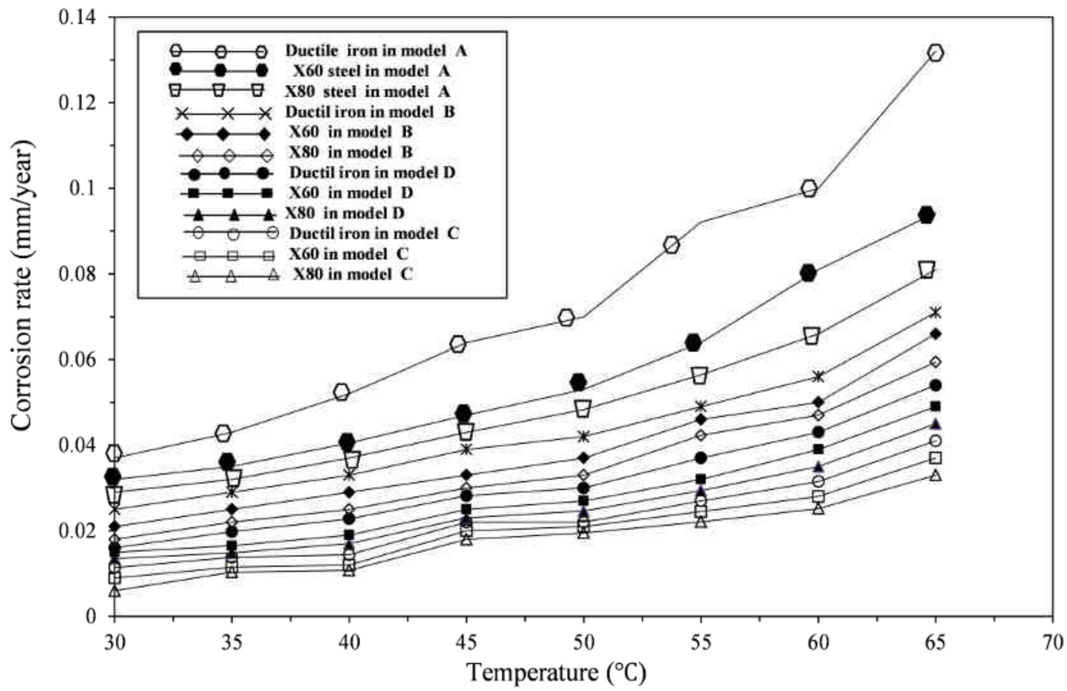


Figure 11: Corrosion rate vs. temperature obtained from immersion test of different inhibitor and materials for Abu Gharab crude oil.

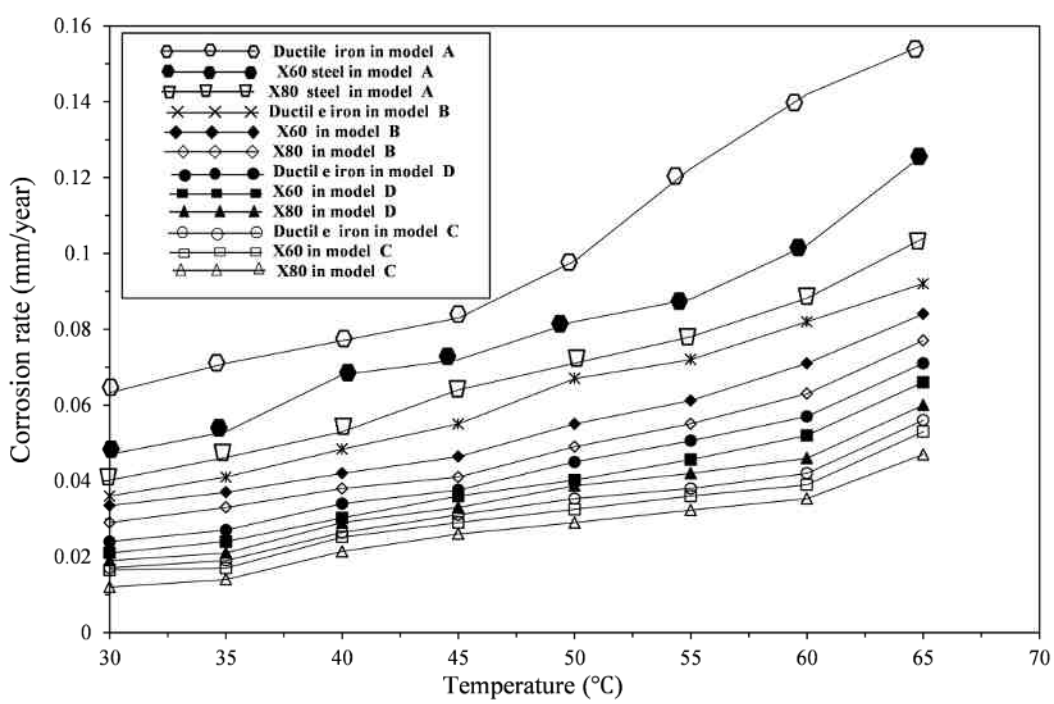


Figure 12: Corrosion rate vs. temperature obtained from immersion test for different inhibitor and materials for Faqa 2 crude oil.

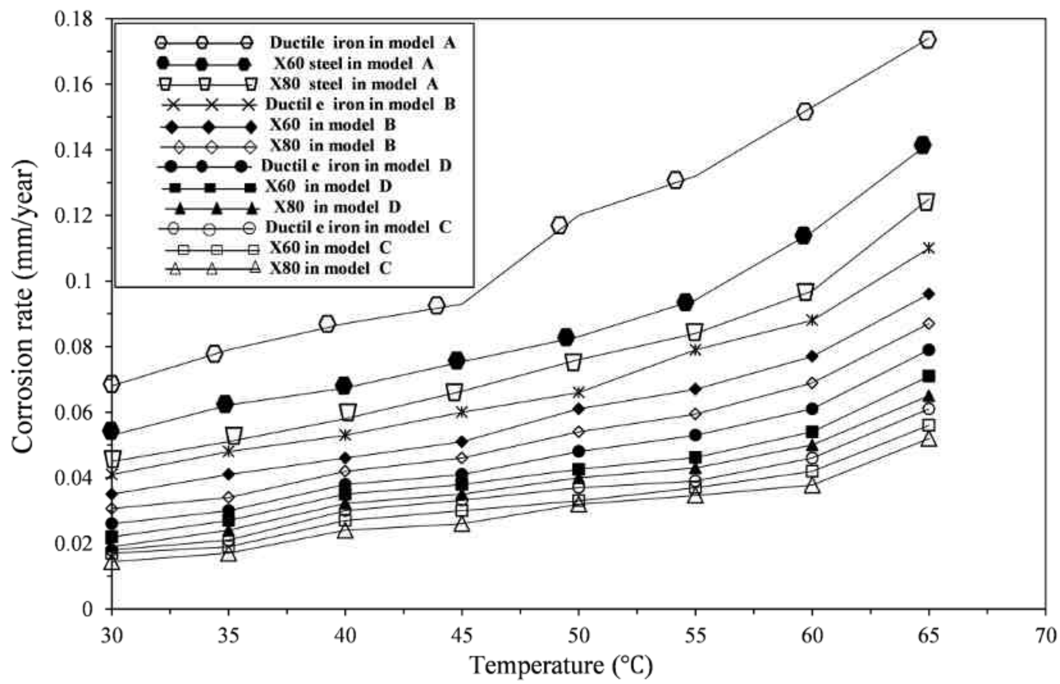


Figure 13: Corrosion rate vs. temperature obtained from immersion test of different inhibitor and materials for Bazurkan crude oil.

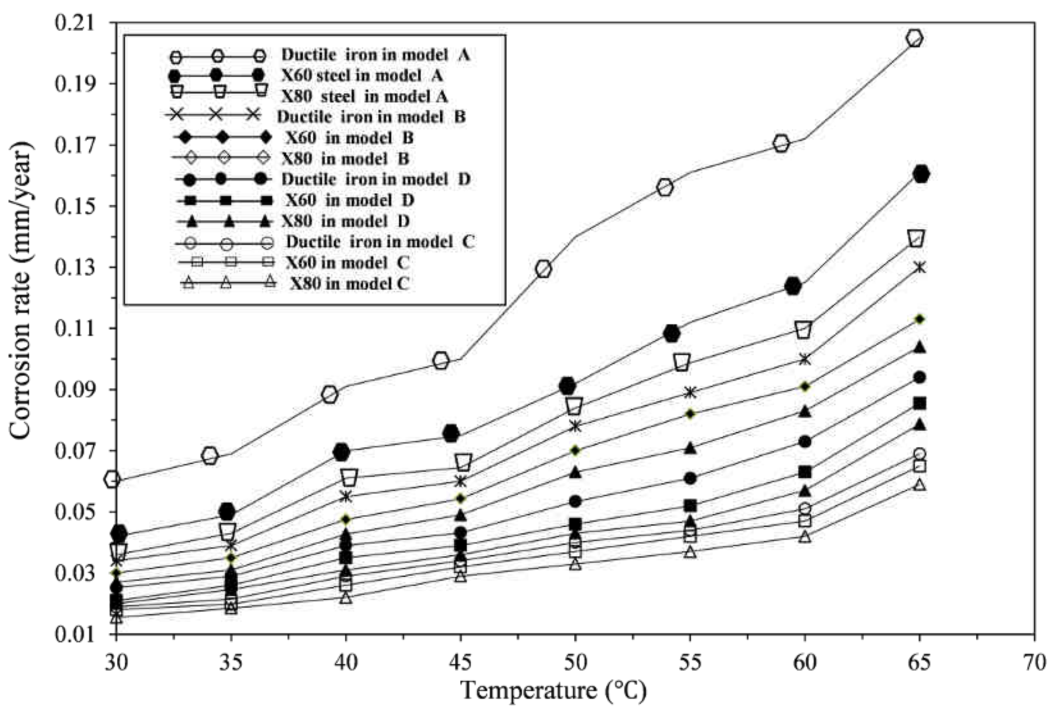


Figure 14: Corrosion rate vs. temperature obtained from immersion testing of different inhibitor and materials in Noor crude oil.

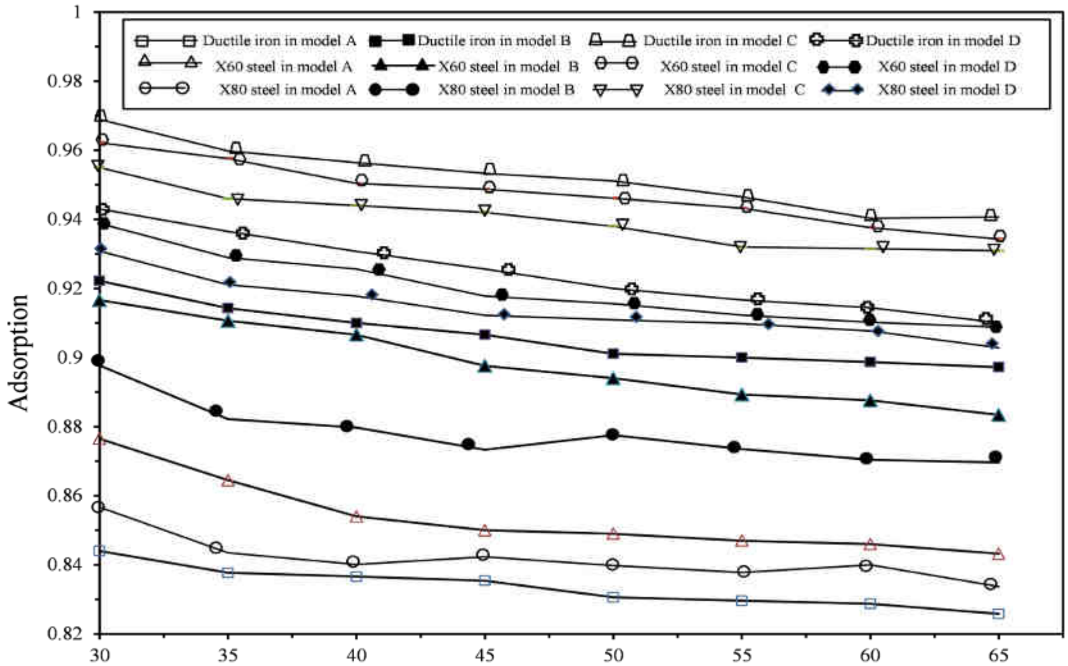


Figure 15: Adsorption vs. temperature of three pipe metals at different temperature in Halfaya crude oil.

Table 8. Corrosion rates and efficiency of inhibitors of various metals and crude oil solution at 65°C.

		Oil fields											
Materials	Inhibitor	Halfaya		Faqa1		Abu Gharab		Faqa2		Bazurkan		Noor	
		C_{ir} mm/y	E_f %	C_{ir} mm/y	E_f %	C_{ir} mm/y	E_f %	C_{ir} mm/y	E_f %	C_{ir} mm/y	E_f %	C_{ir} mm/y	E_f %
Ductile iron	A	0.1	82.58	0.11	82.62	0.132	81.30	0.155	79.36	0.174	78.67	0.205	94.83
	B	0.059	89.72	0.061	90.36	0.071	89.94	0.092	87.75	0.108	86.76	0.131	86.45
	C	0.034	94.07	0.037	94.15	0.041	94.19	0.056	92.54	0.061	92.52	0.069	92.86
	D	0.047	91.01	0.049	92.26	0.053	92.49	0.071	90.54	0.079	90.32	0.094	90.27
X60 steel	A	0.074	84.32	0.081	83.92	0.094	84.88	0.126	81.02	0.142	80.49	0.161	80.92
	B	0.055	88.34	0.058	88.49	0.066	89.38	0.084	87.34	0.096	86.81	0.113	86.61
	C	0.031	93.43	0.034	93.25	0.038	93.89	0.052	92.16	0.057	92.17	0.064	92.42
	D	0.043	90.88	0.046	90.87	0.049	92.12	0.066	90.06	0.071	90.24	0.085	89.93
X80 steel	A	0.065	83.37	0.069	83.68	0.081	85.13	0.104	82.86	0.125	81.48	0.140	80.97
	B	0.051	86.96	0.054	87.23	0.059	89.17	0.077	87.31	0.087	87.11	0.105	85.73
	C	0.027	93.09	0.032	92.43	0.034	93.76	0.048	92.09	0.052	92.29	0.059	91.98
	D	0.038	90.28	0.041	90.31	0.045	91.74	0.061	89.95	0.065	90.37	0.078	89.40

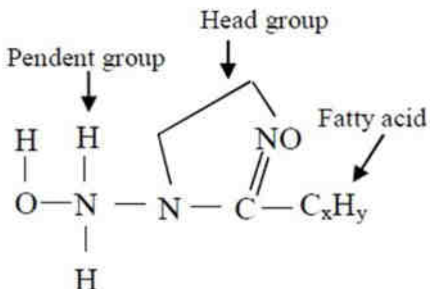


Figure 16: Structure of Imidazoline with fatty acid

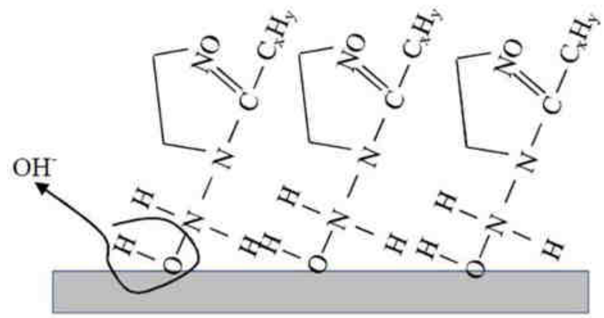


Figure 17: Adsorption Imidazoline with fatty acid on surface.

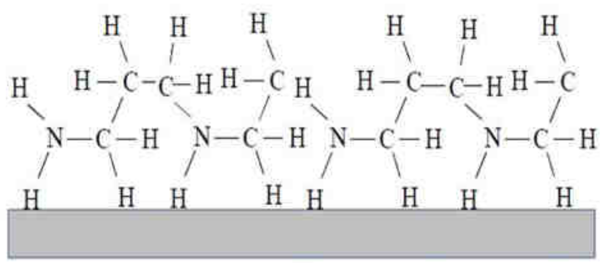


Figure 18: Amine structure and distributed on surface

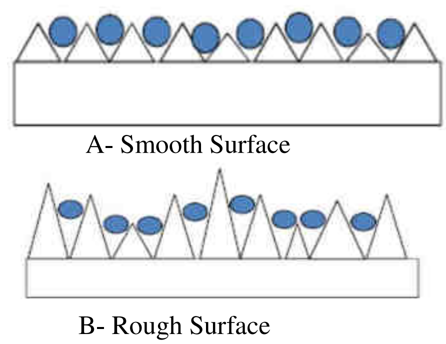


Figure 19: Effect of Roughness on efficiency of corrosion inhibitor and surface coverage

5. Conclusions

Based upon the results of this study, the following concluded can be drawn:

1- The X80 carbon steel shows lower values of corrosion rate while ductile iron shows larger values and X60 carbon steel shows moderate values.

2- The efficiency of the corrosion inhibitor depends on temperature, compositions of crude oil, compositions and types of materials tested.

3- Crude oil of Halfaya fields has lower values of corrosion rate while crude oil of Noor fields has largest values, crude oils of other fields shows moderate’s value.

4- Imidazolines with fatty acids corrosion inhibitor have highest values of corrosion inhibitor efficiency, while Great corrosion inhibitor consists from amine with additives show lower inhibitor efficiency, other types show moderate values.

5- The protection efficiency of corrosion inhibitor is affected by roughness of pipeline metals, as roughness increased lead to decrease the protection efficiency.

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