

Corrosion Inhibition of Thiourea with Synergistic Effect of Potassium Iodide on Mild Steel in Brackish Water and Effluent Water

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Abstract

The corrosion inhibition of mild steel in oilfield brackish water and effluent water has been studied in relation to the concentration of the thiourea (as corrosion inhibitor) as well as the temperature using weight loss method. The mild steel corrosion coupons were processed and evaluated as per international standard procedures i.e. NACE SP-0775 2013 and ASTM G1-03.

The results were supplemented with scanning electron microscopy (SEM) and infra-red (IR) spectroscopy. The presence of C=S group, which enhances the electron density on the molecule acts as the active site for corrosion inhibitor adsorption leading to stronger bond with metal surface through physio-chemical adsorption by the formation of a protective barrier film. Synergetic effect of potassium iodide in corrosive media has been found to stabilize the adsorption, leading to improved inhibition efficiency. The results showed that Thiourea is a good corrosion inhibitor.

Keywords: Thiourea, corrosion inhibitors, mild steel, adsorption process, Scanning Electron Microscopy (SEM), Infrared Spectroscopy (IR) spectra.

Introduction

Industries depend greatly on the use of mild steel due to its good mechanical strength and relatively low cost. Scientists are persistent trying to combat corrosion of metals in many ways.¹ According to Norman E. Hammer, the definition of corrosion inhibitor favored by the National Association of Corrosion Engineers (NACE) is "a substance which retards corrosion in one or more ways to control corrosion by adsorption of a thin film onto the surface of a corroding material, by inducing the formation of a thick corrosion product, or by changing the characteristic of the environment resulting in reduced aggressiveness".

The high costs of corrosion have a significant effect on the national economy. In oil and gas pipelines, content of water and sediments is a good electrolyte to increase the process of corrosion reaction in the presence of oxygen, carbon dioxide and hydrogen sulfide which are the main constituents to promote corrosion which degrades the metal, reduces its strength, thickness and in some extreme cases, creates pits and then holes in the material.²

The use of corrosion inhibitors has considerably increased in recent years due to increased awareness of corrosion worldwide. Organic inhibitors, amongst others, containing polar functional groups with nitrogen, sulphur and/or oxygen atoms in the conjugated system have been reported to exhibit good inhibiting properties. Adsorption mainly depends on large structure, double bonds, an active center or group etc. These features give the molecule ability to cover a large area of a metal surface with a firmly attached film. Inhibitors are adsorbed by the metal surface immersed in an aqueous phase replacing water molecules adsorbed already on the surface. The efficiency of these inhibitors is sometimes improved by the addition of some other compounds as synergistic corrosion inhibitors.³⁻⁵

The aim of this work is to study the corrosion inhibition of Thiourea with Synergistic Effect of Potassium Iodide (KI) on Mild Steel in Brackish Water (BRW) and Effluent Water (EFW). Weight loss method was used for corrosion inhibition efficiency evaluation at different inhibitor concentration and different temperatures. The results were supplemented by MIC, SEM and IR studies.

Material and Methods

Surface Preparation of the Corrosion Coupon: Mild steel refers to low carbon steel which is usually used for structural applications. With too little carbon content to harden, it is weldable which expands the possible applications. The specimens used for corrosion tests were square solid mild steel (MS) coupons with dimension of 2 x 2 cm have been used. Chemical composition of Mild steel coupons (C=0.20%, Mn=1.00%, Si=0.05%, S=0.025%, P=0.25% and Fe=98%) were used.⁶ The surface of the specimens was polished using emery paper (Silicon carbide, grade 200 - 800), rinsed with distilled water, dried and immersed in acetone for 5 seconds and finally dried at room temperature and then weighed. These polished coupons were subjected to water test in agreement as per international standards i.e. NACE SP-0775 2013 and ASTM G1-03 to make sure the metal surfaces were free of scratches and other apparent defects like pits. All reagents that were used for the study were of analytical grades and double distilled water.⁷

Organic Compound: Thiourea is an organosulfur compound. The molecular formula of Thiourea is $\text{CH}_4\text{N}_2\text{S}$, Thiourea was purchased from Sigma- Aldrich and used as the inhibitor alone and with synergistic effect of potassium iodide at 4 ppm. The molecular structure of Thiourea compound is:

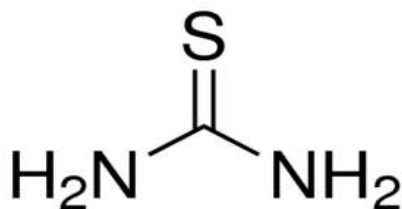


Figure 1: Molecular Structure of Thiourea

Preparation of Thiourea and Potassium Iodide

Solutions: Brackish water and Effluent water was used to make different concentration of 0.1, 0.2 and 0.3 Molarity prepared for thiourea, thiourea with potassium iodide in 50 ml volume. The inhibitor is soluble in water. Parameters of used brackish water and effluent water are compiled in table 1.

Brackish and effluent water were used for weight loss method. From the physicochemical properties of the brackish and effluent water it was determined that in oil field fluids, the higher is concentration of the inorganic ions present, the higher are the chances of corrosion and it is influenced by the following corrosion variables namely: conductivity, total dissolved solids, pH, dissolved gases, intensity of microbiological activities, temperature, pressure and velocity. The parameters to check water quality in brackish water and effluent water are chlorides, carbonate, bicarbonate, sulfates, calcium, magnesium, iron and chloride. Chloride typically represents the most significant percentage of the total dissolved solids to promote extremely aggressive corrosion, particularly localized (pitting, crevice etc.) corrosion. The results obtained are as shown in table 1.

Weight Loss Corrosion Coupon Analysis: The mild steel corrosion coupons were immersed in brackish water and effluent water at different concentrations for 30 days for weight loss. The experiments were carried out to study the corrosion inhibition effects of thiourea with and without synergistic effect of potassium iodide (KI) at different concentrations and temperatures.

In the weight loss experiment, the mild steel coupons were accurately weighed and then immersed in 50 ml of each of test solution contained in a plastic bottle. The first bottle was used as blank and rest were used to contained as corrosion inhibitor at different concentrations of 0.1M, 0.2M and 0.3M prepared for Thiourea, Thiourea with Potassium Iodide and kept at constant temperature $25\pm 1^\circ\text{C}$ throughout the experiment.⁸ After the period of 30 days, the mild steel coupons were removed, scrubbed with 000 grade steel wool in soap solution, degreased with acetone, dried in warm air and re-weighed.

Corrosion coupon test specimens were prepared, cleaned and analyzed as per international standards i.e. NACE SP-0775 2013 and ASTM G1-03. A calculation of average corrosion rate, expressed as uniform rate of thickness loss per unit time in mils per year (mpy), is shown in equation (1):

$$CR = \frac{WX365X1000}{ATDX(2.54)^3} = \frac{2.227X10^4 XW}{ATD} \quad (1)$$

where CR = Average corrosion rate, mils per year (mpy); W = Mass loss, grams (g); A = Initial exposed surface area of coupon, square inches (in²); T = Exposure time, days (d) and D = Density of the coupon metal, grams per cubic centimeter (g/cm³).

General corrosion and pitting (localized corrosion) rates are categorized 'Low, Moderate, High and Severe' as per NACE Guidelines as shown in table 2.

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Corrosion Inhibition Determination through Corrosion Coupons:

The corrosion inhibition efficiency (IE) was calculated using the equation:

$$IE (I\%) = \frac{W_0 - W}{W_0} \times 100 \quad (2)$$

where W_0 is the weight loss in the absence of inhibitor in solution and W is the weight loss in the presence of inhibitor in the solution.

Results and Discussion

Analysis of Weight Loss Study: The effect of inhibition efficiencies (IE) and corrosion rates (CR) of Thiourea in controlling corrosion of mild steel immersed in brackish water and effluent water for a period of 30 days and 1 day of varying concentration of 0.1M, 0.2M and 0.3M at $25\pm 1^\circ\text{C}$ temperature in the absence and presence of KI was studied and it is given in table 3. It was observed that as the increase in the inhibitor concentration was accompanied by a decrease in corrosion rate and an increase in the percentage inhibition efficiency. When compared to 30 days and 1 day in BRW and EFW, there is almost same IE in TU and TU with KI in 30 days but there is a big difference between TU and TU with KI in 1 day. The maximum IE achieved in 30 days in TU 0.3M with KI (4 ppm) shows 87.12% in BRW and 97.08% in EFW respectively.

The calculated value indicates the ability of thiourea to be a good corrosion inhibitor. The IE is found to be enhanced in the presence of KI. This suggests that a synergistic effect exists between thiourea and KI. The inhibition efficiency of corrosion was found to be dependent on the inhibitor concentration. The addition of thiourea reduces metal dissolution in an aqueous environment and this may be due to adsorption and complex formation at the metal surface with the combined application of thiourea and KI. Hence the corrosion process is inhibited⁹ and this can be explained on the basis that halide ions have a greater tendency to be adsorbed on the metal surface in attraction with organic

cations. The large size and ease of polarizability of iodide ion (I^-) facilitate electron pair bonding. The halide ions are first adsorbed by chemisorptions covering greater surface from the stabilization of adsorbed iodide ions by means of electrostatic interaction which facilitates corrosion inhibition synergism on the metal surface and the inhibitor is then drawn in to the double layer by the adsorbed halide ion, such that the ion pair formation occurs directly on the metal surface.

The synergistic ability of the halide increases in the order $Cl^- < Br^- < I^-$. Thus, the interaction enhances the inhibition efficiency to a considerable extent due to the increase of the surface coverage in the presence of iodide ions. Hence the corrosion process is inhibited.¹⁰⁻¹² These results lead to the conclusion that thiourea is fairly efficient as inhibitor for mild steel dissolution in BRW and EFW.

Effect of temperature: Temperature has a great effect on the corrosion phenomenon. The effect of temperature on the corrosion rate and inhibition efficiency of mild steel in BRW and EFW in absence and presence of different concentrations from 0.1M to 0.3M of thiourea alone and with synergistic effect of thiourea and KI (4ppm) was studied in the temperature range of (25°C, 30°C, 40°C and 50°C) for 1 day using weight loss measurements. As the temperature increases, the rate of corrosion increases as shown in table 4 and 5. This may be ascribed to desorption of the inhibitors molecules at higher temperatures, thus exposing the metal surface to further attack. It has been clearly distinguished from the figures 1, 3, 5 and 7 that the corrosion rate increases almost 2 times with the rise in temperature from 25°C to 50°C in BRW and EFW.

Table 1
Quality of Used Brackish and Effluent Water

Test Parameters	Unit	Brackish Water	Effluent Water
Color/Appearance		Clear	Slight Black
pH		7.2	6.6
Conductivity	$\mu S/cm$	4560	292000
H ₂ S Content (Water)	dm^{-3}	0.005	8.7
Total Dissolved Solids	dm^{-3}	2376	151600
Salt content as NaCl	dm^{-3}	1188	33500
Cl ⁻ Content	dm^{-3}	720	89972
Hardness as CaCO ₃	dm^{-3}	2000	33500
Ca ²⁺ Content	dm^{-3}	560	9400
Mg ²⁺ Content	dm^{-3}	146	2430
SO ₄ ²⁻ Content	dm^{-3}	1275	200
Fe Cont. (Total)	dm^{-3}	2.5	1.3
Fe Cont. (Dissolved)	dm^{-3}	0.23	1.2
Mn Content	dm^{-3}	0.02	0.7
M. Alkalinity as CaCO ₃	dm^{-3}	120	280
HCO ₃ ⁻ Content	dm^{-3}	146	342

Table 2
Classification of Corrosion and Pitting Rates as per NACE SP0775-2013 (mpy = mills per year)

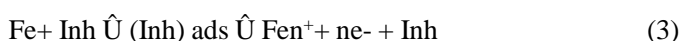
General Corrosion Category	Corrosion Rate (mpy)	Pitting Corrosion Category	Pitting Rate (mpy)
Low	< 1	Low	< 5
Moderate	1 to 4.9	Moderate	5 to 7.9
High	5 to 10	High	8 to 15
Severe	> 10	Severe	> 15

Inhibition Efficiency and Degree of Surface Coverage:

Inhibition efficiency decreases as temperature increases at the same time with increase in concentration inhibition efficiency increases as shown in figures 2, 4, 6 and 8. The result shows that the increase in efficiencies with increase in inhibitors concentration was due to increase of the number of molecules adsorbed onto mild steel surface and reduces the surface area on the metal surface. The higher corrosion inhibition efficiency is due to the higher surface coverage. The adsorption behavior of inhibitors on mild steel surface occurs through physical adsorption.¹³ The corrosion reactions are prevented from occurring over the area (or active sites) of the metal surface covered by adsorbed inhibitor species whereas these corrosion reactions occurred normally on the inhibitor free area.

So, it is assumed that the inhibitor molecules formed a protective layer on the metal/solution interface consequently, the fraction of surface covered with inhibitor species ($\theta = IE\%$) can be followed as a function of inhibitor concentration and solution temperature. The surface coverage (q) data are very useful while discussing the adsorption characteristics. When the fraction of surface covered is determined as a function of the concentration at constant temperature, adsorption isotherm can be evaluated at equilibrium condition. The dependence of the fraction of the surface covered q on the concentration C of the inhibitor can be explained by Langmuir's adsorption isotherm which assumes that the solid surface contains a fixed number of adsorption sites and each site holds one layer of adsorbed species.

Mechanism of Corrosion Inhibition: According to Bockris and Drazic, the inhibition mechanism could be explained by Fe-(Inh) ads reaction intermediated as below equation 3.



The adsorbed layer combats the action of brackish and effluent water solutions and enhances protection of the metal surface. When there is sufficient Fe-(Inh) ads to cover the metal surface (if the inhibitor concentration was low or the adsorption rate was slow), metal dissolution would take place at sites on the mild steel surface free of Fe-(Inh) ads which are free of Fe-(Inh) ads.

With high inhibitor concentration a compact and coherent inhibitor over layer forms on mild steel surface, reducing chemical attack on the metal. The adsorption of an organic molecule on the surface of the mild steel is regarded as a substitution of adsorption process between the organic compound in the aqueous phase (Orgaq) and the water molecules adsorbed on the mild steel surface (H₂Oams). Orgaq + x H₂Oams \rightleftharpoons Orgams + x H₂Oaq, where x is the size ratio in terms of the number of water molecules replaced by an adsorbate molecule.

The adsorption of the inhibitor molecules on the metal surface is due to the donor – acceptor interaction between π electrons of donor atoms O, N and aromatic rings of the extract compounds structures of the inhibitor and the acceptor i.e. vacant d orbital of carbon steel surface atoms. The inhibitor molecules also can be adsorbed in the form of negatively charged species on the metal surface which can interact electrostatically with positively charged metal surface, leading to increase the surface coverage and consequently protect efficiency controlling the anodic metal dissolution and cathodic hydrogen evolution.¹⁴

Analysis of FTIR spectra: Fourier transform infra-red spectroscopy Perkin-Elmer 'Spectrum Two' Spectrophotometer (spectral resolution 0.5 cm⁻¹) was used to record the FT-IR spectra of pure Thiourea and Thiourea adsorbed on the carbon steel surface. The carbon steel specimens were immersed in various test solutions for one week were taken out cleaned and dried first and the thin film formed on the metal surface was carefully removed. To record the FT-IR spectra of pure Thiourea, the powder was mixed with KBr and made into the disc. The spectra were recorded in the frequency range of 1800–200 cm⁻¹. Data was collected and interpreted by the Spectrum Software.¹⁵

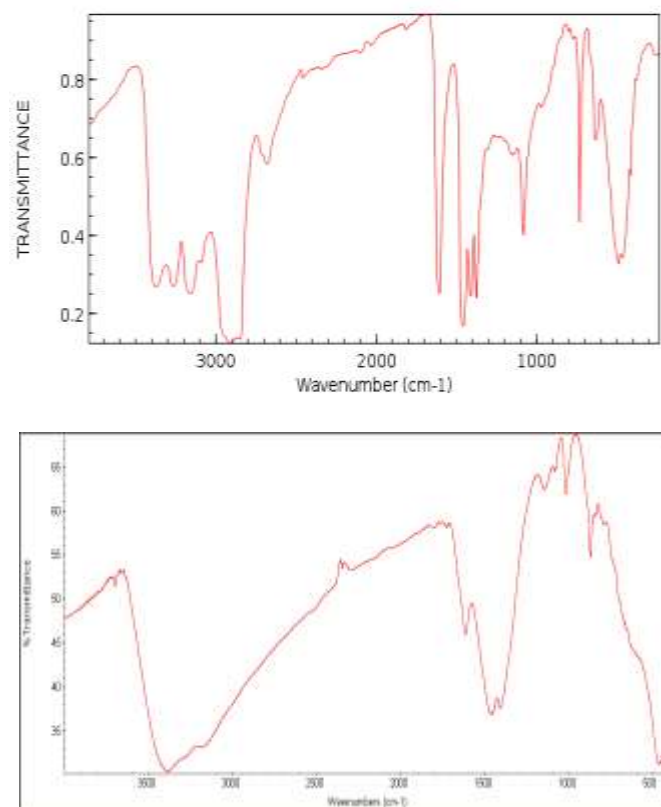


Fig. 1: (a) FTIR Spectrum of pure Thiourea, (b) film formed on the metal surface

The FTIR spectrum of pure thiourea is shown in fig. 1 (a). The spectrum was recorded between the frequencies 200 and 4000 cm⁻¹. In between the higher energy region 3395 to 2033 cm⁻¹, the NH₂ asymmetric stretching mode is observed at 3395 cm⁻¹. The NH stretch mode is observed at 3179 cm⁻¹.

The NH_2 stretching mode 97 is observed at 2674 cm^{-1} . The NCN , NH_3^+ stretching mode is observed at 2104 cm^{-1} . The NH_2 bending mode is observed at 1621 cm^{-1} . The CN asymmetric stretching mode is observed at 1464 cm^{-1} . The C S asymmetric stretching mode is observed at 1395 cm^{-1} . The CN symmetric stretching mode is observed at 1089 cm^{-1} . The C S symmetric stretching mode is observed at 729 cm^{-1} . The NCN asymmetric bending mode is observed at 485 cm^{-1} .

The FTIR spectrum of the film formed on the metal surface is shown in fig. 1 (b). The $\text{C}=\text{S}$ stretching frequency has shifted from 1677 cm^{-1} to 1613 cm^{-1} . The $\text{N}-\text{H}$ stretching frequency has shifted from 3455 cm^{-1} to 3434 cm^{-1} . The $\text{N}-\text{H}$ deformation frequency at 1625 cm^{-1} has completely been minimized to almost invisible. This indicates that the thiourea has coordinated with Fe^{2+} on the metal surface through oxygen atom of $\text{C}=\text{S}$ group and nitrogen atom of $\text{N}-\text{H}$ group resulting in the formation of Fe^{2+} - thiourea complex. Thus, the FTIR study leads to the conclusion that the protective film consists of Fe^{2+} - thiourea complex formed on the metal surface.

Scanning Electron Microscopy (SEM): Polished carbon steel specimens was tested in minimum and maximum inhibitor solutions in oil field water at room temperature for 30 days to check efficiencies of corrosion inhibitor by different concentrations. Then the corrosion coupons would be washed with distilled water, dried in desiccator and would be subjected to Scanning Electron Microscopic examination.

Surface Morphological Studies Surface analysis was performed using Scanning Electron Microscope. The corrosion coupons were washed with distilled water, dried in desiccator and then subjected to Scanning Electron microscopic examination. SEM images were obtained from MS surface after the immersion in 0.3 M in BRW and EFW in the absence and presence of Thiourea for 30 days at room temperature.

Flakes which show corrosion products are observed in the micrographs. The electron micrographs (SEM) reveal that the surface was strongly damaged owing to corrosion in absence of the Thiourea, but in the presence of the Thiourea there is a much smaller damage on the surface. This is attributed to the formation of a good protective film on the carbon steel surface. It is quite apparent from the micrographs the uniform products like metal hydrides and their oxides are also visible.

Microbiologically Induced Corrosion Analysis (MIC): MIC is common issue in oil industries. The efficiencies of corrosion inhibitor are checked by the evolution of MIC through bacterial counting. Serial dilution media specific to SRB, GAB and GAnB are used for bacterial growth analysis as per NACE TM0194-2004. Bacteria like sulfate reducing bacteria (SRB), general aerobic bacteria (GAB) and general anaerobic bacteria (GAnB) are the most common bacteria

encountered in most oil fields. These bacteria cause microbiologically influenced corrosion (MIC).



MIC in oil industry is a most serious problem and microorganisms are present within the structure of the biofilm.¹⁶ Guidelines for quantifying bacterial proliferation are summarized in table 7 and planktonic bacterial data are provided in table 6. The above guidelines imply that the population of the different strains of bacteria in an operating system should be maintained below their target values. The target values provide means of assessing the efficacy of any biocide treatment program that may be in place and serves as a basis for biocide dosage control. As per table 6, no SRB is present but low GAB and GAnB in effluent water but excessive SRB counts in brackish water and low GAB and GAnB bacterial strains. But after treatment with Thiourea no strains were found either in brackish water or effluent water.

Table 3
Corrosion Rate, Inhibition Efficiency and Surface Coverage of Thiourea, Thiourea with Potassium Iodide after one day and after 30 days in Brackish Water and Effluent Water

Brackish Water					
Concentration	Time (days)	Wt. Loss	CR	% IE	θ
Blank	1	0.0025	1.26	0	0.000
Thiourea	0.1	0.0011	0.55	56.00	0.560
	0.2	0.001	0.5	60.00	0.600
	0.3	0.0008	0.4	68.00	0.680
Blank	1	0.0025	1.26	0.00	0.000
Thiourea + KI	0.1	0.0009	0.45	64.00	0.640
	0.2	0.0005	0.25	80.00	0.800
	0.3	0.0003	0.15	88.00	0.880
Blank	30	0.1848	2.38	0.00	0.000
Thiourea	0.1	0.0313	0.40	83.06	0.830
	0.2	0.0293	0.38	84.15	0.841
	0.3	0.0257	0.33	86.09	0.860
Blank	30	0.1848	2.38	0.00	0.000
Thiourea + KI	0.1	0.0302	0.39	83.66	0.836
	0.2	0.0268	0.35	85.50	0.855
	0.3	0.0238	0.31	87.12	0.871
Effluent Water					
Concentration	Time (days)	Wt. Loss	CR	% IE	θ
Blank	1	0.0012	0.60	0.00	0.000
Thiourea	0.1	0.0008	0.40	33.33	0.333
	0.2	0.0006	0.30	50.00	0.500
	0.3	0.0004	0.20	66.67	0.666
Blank	1	0.0012	0.60	0.00	0.000
Thiourea + KI	0.1	0.00075	0.38	37.50	0.375
	0.2	0.00058	0.29	51.67	0.516
	0.3	0.0003	0.15	75.00	0.750
Blank	30	0.439	7.35	0.00	0.000
Thiourea	0.1	0.0223	0.29	94.92	0.949
	0.2	0.0204	0.26	95.35	0.953
	0.3	0.0131	0.17	97.02	0.970
Blank	30	0.439	7.35	0.00	0.000
Thiourea + KI	0.1	0.0222	0.29	94.94	0.949
	0.2	0.0189	0.24	95.69	0.956
	0.3	0.0128	0.17	97.08	0.970

Table 4
Corrosion Rate, Inhibition Efficiency and Surface Coverage of Thiourea, Thiourea with Potassium Iodide at Different Temperatures in Effluent Water

Effluent Water						
Conc	Temp	Wt Loss	CR	% IE	θ	
Blank	25	0.0012	0.60	0.00	0.000	
Thiourea	0.1	25	0.0008	0.40	33.33	0.333
	0.2	25	0.0006	0.30	50.00	0.500
	0.3	25	0.0004	0.20	66.67	0.666
Blank	30	0.0015	0.75	0.00	0.000	
Thiourea	0.1	30	0.0011	0.55	26.67	0.266
	0.2	30	0.0008	0.40	46.67	0.466
	0.3	30	0.0006	0.30	60.00	0.600
Blank	40	0.0026	1.41	0.00	0.000	
Thiourea	0.1	40	0.00195	0.98	25.00	0.250
	0.2	40	0.0015	0.75	42.31	0.423
	0.3	40	0.0013	0.65	50.00	0.500
Blank	50	0.0028	2.31	0.00	0.000	
Thiourea	0.1	50	0.0022	1.10	21.43	0.214
	0.2	50	0.0019	0.95	32.14	0.321
	0.3	50	0.0017	0.85	39.29	0.392
Blank	25	0.0012	0.60	0.00	0.000	
Thiourea + KI	0.1	25	0.00075	0.38	37.50	0.375
	0.2	25	0.00058	0.29	51.67	0.516
	0.3	25	0.0003	0.15	75.00	0.750
Blank	30	0.0015	0.75	0.00	0.000	
Thiourea + KI	0.1	30	0.001	0.50	33.33	0.333
	0.2	30	0.00075	0.38	50.00	0.500
	0.3	30	0.00055	0.28	63.33	0.633
Blank	40	0.0026	1.41	0.00	0.000	
Thiourea + KI	0.1	40	0.0017	0.85	34.62	0.346
	0.2	40	0.00145	0.73	44.23	0.442
	0.3	40	0.00125	0.63	51.92	0.519
Blank	50	0.0028	2.31	0.00	0.000	
Thiourea + KI	0.1	50	0.0018	0.90	35.71	0.357
	0.2	50	0.0017	0.85	39.29	0.392
	0.3	50	0.0015	0.75	46.43	0.464

Table 5
Corrosion Rate, Inhibition Efficiency and Surface Coverage of Thiourea, Thiourea with Potassium Iodide at Different Temperatures in Brackish Water

Brackish Water						
Conc	Temp	Wt Loss	CR	% IE	θ	
Blank	25	0.0025	1.26	0.0	0.0	
Thiourea	0.1	25	0.0011	0.55	56.00	0.560
	0.2	25	0.001	0.5	60.00	0.600
	0.3	25	0.0008	0.4	68.00	0.680
Blank	30	0.0037	1.86	0.00	0.000	
Thiourea	0.1	30	0.0017	0.85	54.05	0.540
	0.2	30	0.0016	0.80	56.76	0.567
	0.3	30	0.0015	0.75	59.46	0.594
Blank	40	0.0045	2.26	0.00	0.000	
Thiourea	0.1	40	0.0024	1.20	46.67	0.467
	0.2	40	0.0023	1.10	48.89	0.489
	0.3	40	0.0019	0.95	57.78	0.578
Blank	50	0.0065	3.26	0.00	0.000	
Thiourea	0.1	50	0.0037	1.86	43.08	0.430
	0.2	50	0.00355	1.78	45.38	0.453
	0.3	50	0.0029	1.46	55.38	0.553
Blank	25	0.0025	1.26	0.00	0.000	
Thiourea + KI	0.1	25	0.0009	0.45	64.00	0.640
	0.2	25	0.0005	0.25	80.00	0.800
	0.3	25	0.0003	0.15	88.00	0.880
Blank	30	0.0037	1.86	0.00	0.000	
Thiourea + KI	0.1	30	0.0016	0.80	56.76	0.567
	0.2	30	0.0014	0.70	62.16	0.621
	0.3	30	0.0013	0.65	64.86	0.648
Blank	40	0.0045	2.26	0.00	0.000	
Thiourea + KI	0.1	40	0.0023	1.15	48.89	0.488
	0.2	40	0.00185	0.93	58.89	0.589
	0.3	40	0.0018	0.90	60.00	0.600
Blank	50	0.0065	3.26	0.00	0.000	
Thiourea + KI	0.1	50	0.0035	1.76	46.15	0.461
	0.2	50	0.0029	1.46	55.38	0.553
	0.3	50	0.0027	1.36	58.46	0.584

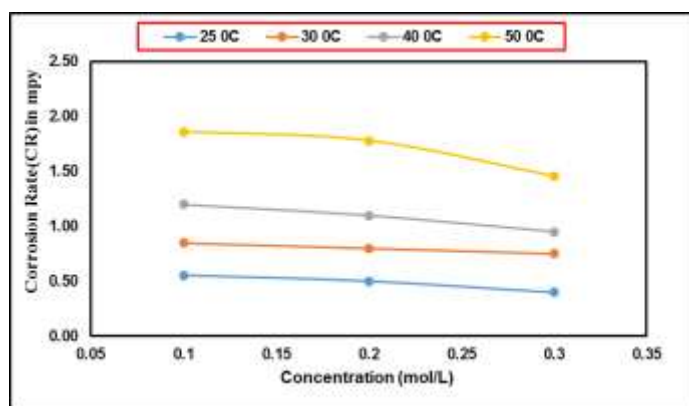


Figure 2: Corrosion rate versus concentration at different temperature for thiourea at 24 h exposure in brackish water

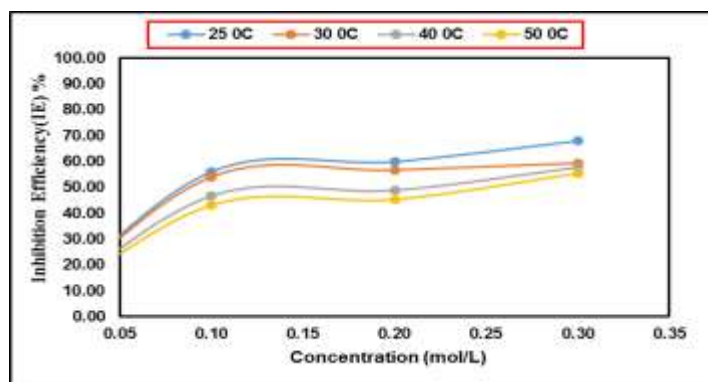


Figure 3: Efficiency versus concentration at different temperature for thiourea at 24 h exposure in brackish water

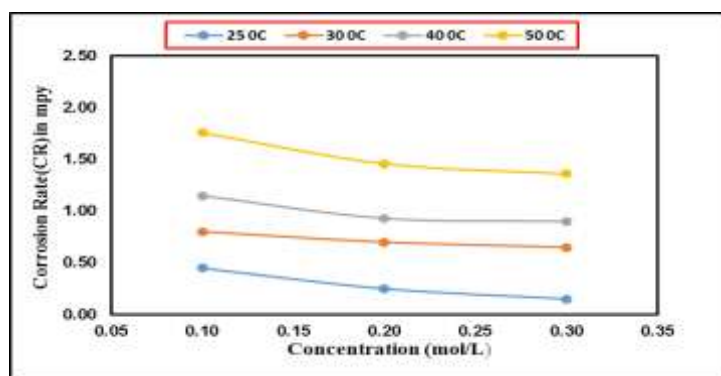


Figure 4: Corrosion rate versus concentration at different temperature for thiourea + KI at 24 h exposure in brackish water

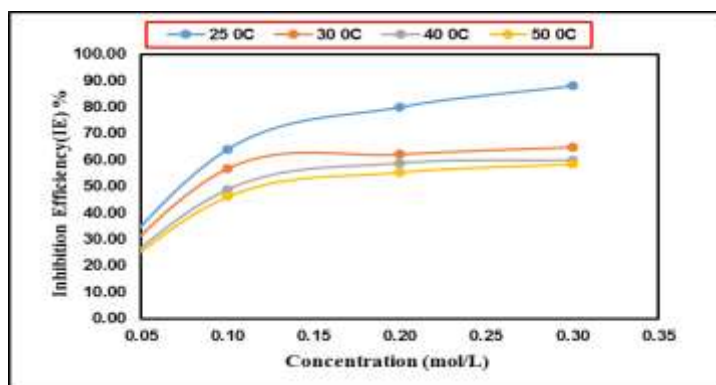


Figure 5: Efficiency versus concentration at different temperature for thiourea + KI at 24 h exposure in brackish water

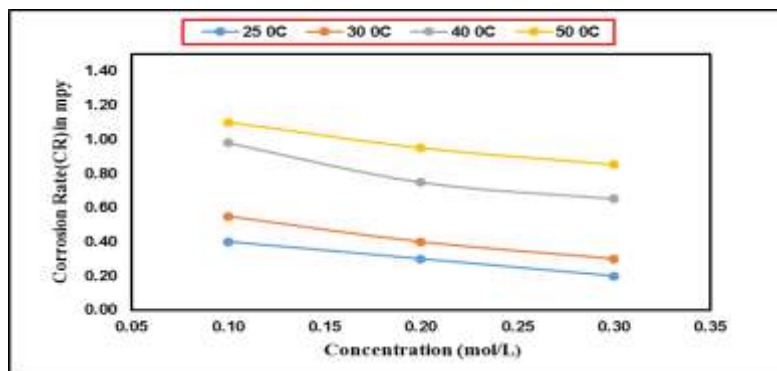


Figure 6: Corrosion rate versus concentration at different temperature for thiourea at 24 h exposure in Effluent water

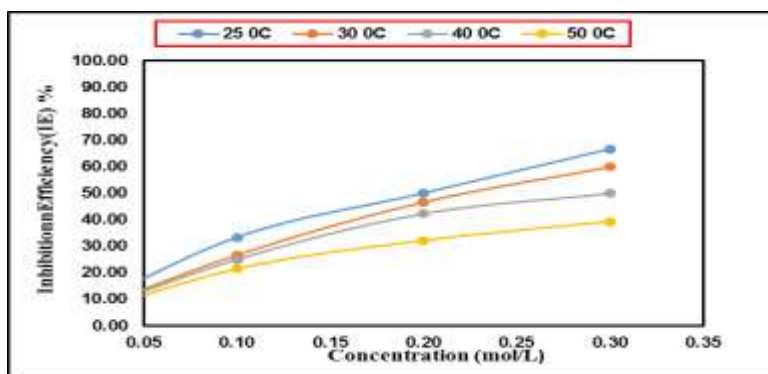


Figure 7: Efficiency versus concentration at different temperature for thiourea at 24 hours exposure in effluent water

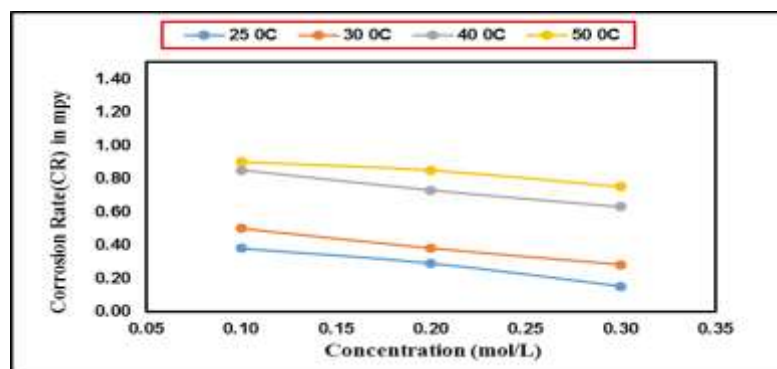


Figure 8: Corrosion rate versus concentration at different temperature for Thiourea with KI at 24 hours exposure in Effluent Water

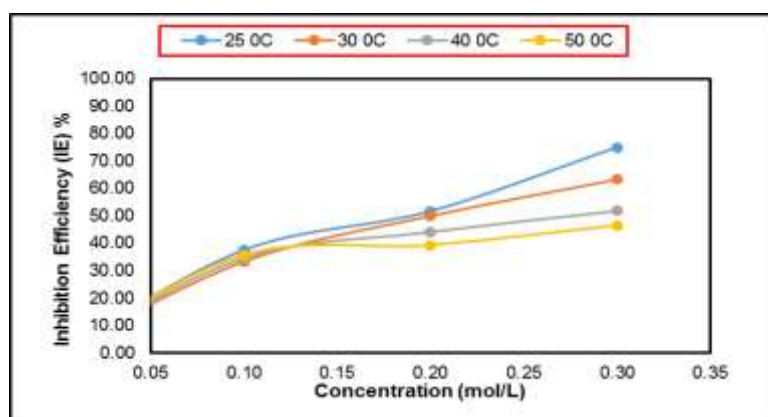


Figure 9: Efficiency versus concentration at different temperature for thiourea + KI at 24 hours exposure in effluent water

Table 6
Planktonic Bacterial Counts Data

Samples	Suphur Reducing Bacteria (SRB)	General Aerobic Bacteria (GAB)	General Anaerobic Bacteria (GAnB)
Blank Brackish Water	10	1000	100
Brackish Water with Thiourea	0	0	0
Blank Effluent water	0	10	10
Effluent water with Thiourea	0	0	0

Table 7
Reference for Planktonic Bacterial Limit

Bacteria Type	Planktonic Bacteria
SRB	<1 counts per ml
GAB/APB	<10 ⁴ counts per ml
GAnB	<10 ⁴ counts per ml

From the results of table 6, it is clear that microbial growth is almost stopped by adsorbed layer of inhibitor, this is an additional factor to prevent corrosion or deteriorating of quality of mild steel by biofouling.

Conclusion

This research investigated the phenomenon of corrosion of mild steel metal in brackish water and effluent water. Weight loss method, temperature measurements FT-IR, MIC and SEM were used in this study. The following conclusions were derived:

- Thiourea acts as good inhibitor for mild steel in BRW and EFW.
- From the weight loss study, it is showed that strong electrostatic interaction between the mild steel surface and thiourea through physio-chemical adsorption occurred in the inhibition process.
- The corrosion rates of mild steel generally increased with increasing temperature.
- Corrosion rate decreased with thiourea addition in BRW and EFW and inhibition efficiency reaches to 68.48 in thiourea and 69.57 in thiourea with KI in BRW respectively, 97.02 in thiourea and 97.08 in thiourea with KI in EFW respectively.
- Inhibition efficiency increased with increase in thiourea concentration.
- The combination of thiourea and KI indicates that a synergistic effect exists between them which enhances the corrosion inhibition synergism on the metal.

- The metallographic micrographs showed that the morphology pits of mild steel in the absence of thiourea demonstrated a higher number than that in the presence of inhibitor.
- Thiourea control planktonic bacterial strain in effluent water as well as in brackish water.

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