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Unveiling the Effect of Polymer on Pipeline Corrosion

Tinuola H. Udoh

Department of Chemical/Petrochemical Engineering, Akwa Ibom State University, Ikot Akpaden, Akwa Ibom, Nigeria.

Corresponding author e-mail: tinuolaudoh@aksu.edu.ng

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Abstract

This study unveiled the corrosion modification potential of an enhanced oil recovery polymer on flowline material in different saline environments. Polymers such as xanthan gum are usually used to control the mobility of the displacing fluid during flooding process to achieve better sweep efficiency. These polymers and brines are normally transported through flowlines into and from reservoirs, but their effect on flowline materials is not known. The weight loss method was used to study the corrosion rates of mild steel of known weights that were exposed to 0%, 10%, 50%, and 100% formation brine environments and varied concentrations (0.5%, 1%, 3%, and 5%) of xanthan gum for a total period of 432 hours. The results showed that the corrosion rate of mild steel increases with increase in exposure time, but the use of xanthan gum generally reduced the corrosion rates. Also, the corrosion rate of mild steel reduces with an increase in the concentrations of xanthan gum. Furthermore, higher corrosion inhibition efficiencies (>70%) were observed in 10% formation brine environment and the effective corrosion inhibition concentration of xanthan gum was found to be 1 wt.% in all saline environments investigated. Conclusively, from the results of this study, it is evident that the application of xanthan gum polymer commonly used in the enhanced oil recovery process has the potential to reduce the corrosion rate of mild steel in saline environments. The result of this study is significant for the design of polymer-enhanced oil recovery operations.

Introduction

Polymers are commonly added to aqueous solutions to yield viscoelastic solutions of various degrees depending on the concentration of the polymer used. These polymeric solutions are used in enhanced oil recovery to control the mobility of water during the oil displacement process. The efficiency of polymers is however influenced by varied factors such as temperature and salinity that are prevalent in hydrocarbon reservoirs. The reservoir formation brine and the injection brines that are usually encountered and used during the oil production process contain salts of different compositions and concentrations. Previous studies have shown that polyacrylamides or synthetic polymers that are usually produced by the polymerization of acrylamide monomers are more sensitive to brine salinity than polysaccharides or biopolymers that are produced through microbial action of organisms [1, 2]. The use of polymers such as xanthan gum for EOR means a significant reduction in the amount of water required to be injected into reservoirs [3]. However, the effect of polymers on flowlines through which they flow has not been considered by many researchers. The injection and production fluids are usually transported through flowlines or pipelines that are usually associated with corrosion problems.

When metals like flowlines interact with different ions and molecules such as water, chloride, sulfate, oxygen, etc. in their environments, they usually undergo some changes in their chemical composition that will result in corrosion initiation on their surfaces. Galvanic cell reaction which may be anode reaction or cathode reaction at the metal surface is said to be responsible for metallic corrosion. This reaction can however be slowed down by corrosion inhibitors due to the interference in the reaction process [4]. Corrosion is commonly regarded as the degradation of metallic materials through chemical or electrochemical reaction with its environment. In chemical reaction corrosion, the presence of electrolyte in the environment is necessary, but in electrochemical reaction correction, this is not a necessity [5, 6]. Flowline corrosion is the deterioration of pipe material and the related system due to its interaction with the working environment [7]. Previous studies have investigated the corrosion inhibition potential of different types of polymers such as chitosan [8-10], cellulose [11, 12], starch [13], protein [14], gum Arabic [15] etc. and their results showed a positive corrosion inhibition of polymers. Adsorption of polymers on the metal surface is the major mechanism by which they inhibit the corrosion process and the main functional groups responsible for this adsorption are amino (-NH2), carboxyl (-COOH), and phosphate (-PO3H2) [16]. These functional groups also improve their solubility in polar electrolytes [4].

Of interest in this study is a low-cost biopolymer (xanthan gum) that is environmentally friendly, and highly stable in different environments. Xanthan is anionic in nature due to presence of negatively charged carboxyl (-COOH) functional groups in its side chain. When in aqueous solutions, xanthan gum undergoes conformational changes that are influenced by the nature of the solutions such as temperature, salinity, and deformation stress etc. [17]. Xanthan gum exhibits ordered double-helical conformation in aqueous solutions and the presence of ions in the solution usually increase the stability of the conformation. For example, divalent cations like calcium ion adhere strongly to xanthan gum and enhances the stability of the helical conformation. Also, the ordered helical structure of xanthan gum gives it thermal stability and high resistance to hydrolysis [18]. The stability of xanthan in electrolyte solutions is due to reduced intra-molecular electrostatic repulsion in xanthan gum backbone because of the salt ions in the solution. It also has the tendency to undergo self-association hydrogen bonding, hydrophobic association, and cation bridging [18]. A lot of people have conducted research on the use of xanthan gum to control brine mobility in EOR processes, but its effect on flowline materials is not known. In this work, the effect of xanthan gum on corrosion process of flowline materials in saline environment was investigated. [13]

Materials and Methods

Saline solutions preparation

The saline solutions were prepared in similar way to the one in research by Udoh and Benson [19] using Kolo oilfield brine formation with 32 g/L salinity. Kolo field brine has compositions of 98.2% sodium chloride, 0.6% calcium chloride, 0.8% magnesium carbonate, 0.2% sodium sulphate and 0.2% potassium chloride. Three types of saline environments (10%, 50% and 100% formation brine) were considered during this study. These three salinities selected as saline environments are typical salinities of brines used for water injection during production and formation brine in the hydrocarbon reservoir. Table 1 below shows the breakdown of these compositions.

Metal coupon preparation

The material used as a representative of a flowline in this study is mild steel. The metallic material was cut into coupons of the same dimension (4cm by 4cm). The surface of each coupon was then smoothened with emery paper having a grit size of 220 and cleaned with methanol, before drying. The compositional breakdown of the material used is presented in Table 2 below. The coupons had a number attached to each vessel they were immersed in.

Table 1 Compositional breakdown of saline solutions.

Salts	100% salinity Conc. (g/L)	50% salinity Conc. (g/L)	10% salinity Conc. (g/l)
Sodium-chloride ($NaCl$)	31.424	15.712	3.1424
Magnesium carbonate ($MgCO_3$)	0.256	0.128	0.0256
Calcium-chloride ($CaCl_2$)	0.192	0.096	0.0192
Sodium-sulphate anhydrate (Na_2SO_4)	0.064	0.032	0.0064
Potassium chloride (KCl)	0.064	0.032	0.0064

Table 2 Percentage composition of mild steel [5]

Component	%
C	0.150 – 0.190
Mn	0.60 – 0.9
P	≤ 0.025
S	≤ 0.02
Si	≤ 0.03
Cr	≤ 0.15

Polymer

The polymer used in this study is xanthan gum which is a polysaccharide polymer that is produced through fermentation of fructose or glucose by bacteria. It is commonly used in enhanced oil recovery operations to control the mobility of the displacing fluid due to its high resistance to temperature. As mentioned before, a solution of xanthan gum shows a good resistance to temperature variations, pH, and salt concentration. The polymer concentrations used are 0 wt.%, 0.5 wt.%, 1 wt.%, 3 wt.%, and 5 wt.%. The stock solution of polymer was prepared using one litter of deionized water and 10 g of xanthan gum. To get the volume of polymer desired for the preparation of other polymer concentration solutions, Equation 1 was used [19].

$$C_1V_1 = C_2V_2, \tag{1}$$

where C_1 is the initial concentration of polymer solution, C_2 is the final concentration of the polymer concentration, V_1 is the desired volume of the polymer solution and V_2 is the known volume of the solvent (water or saline solution).

Experimental method

Three main experimental variables were considered in this study. Firstly, the effect of contact time of polymer on the flowline material; secondly, effect of varied concentrations of polymer on flowline material and finally, the effect of salinity variations (10%, 50% and 100% formation brine) on flowline material. The experimental method used in this study is weight loss method. This method involves weighing the prepared coupons before and after immersion in relevant solutions using a four decimal places Ohaus weighing balance. The coupons were subjected to constant reweighing after every 72 hours of continuous contact with the relevant environment to check for weight loss. Prior to the commencement of the tests, the mild steel sheet was cut into coupons of the same size and each of the coupons was smoothened using emery paper, cleaned with methanol, dried, and weighed using a weighing balance. Each of the coupons was then immersed in 100 mL relevant saline solutions to which the polymer of varied concentrations was added. The differences in the weights of the coupons before and after immersion were used to calculate the corrosion rate (CR), the corrosion modification efficiency of polymer (E) and the surface coverage of polymer (θ) using Equations 2-4 [5, 20]:

$$CR = \frac{W}{At}, \quad (2)$$

$$E\,(\%) = \frac{CR_0 - CR}{CR_0} x\, 100, \quad (3)$$

$$\theta = \frac{CR_0 - CR}{CR_0}, \quad (4)$$

where W is difference in initial and final weights of coupons (mg), A is area of the coupons in cm^2 and t is the immersion time (h) of the coupons in the solutions, CR_0 and CR are the corrosion rates ($mg cm^{-2} h^{-1}$) without and with inhibitors, respectively.

Results and discussions

Figure 1 presents the results of the sets of tests in which the mild steel coupons were exposed to deionized water with and without polymer addition for a period of 432 hours. The corrosion rate of mild steel in deionized water was calculated from the difference in the weights of the coupons before and after immersion in the solutions. The rate of corrosion of mild steel in deionized water without polymer was used as base case for comparison of corrosion inhibition in the presence of polymer. Based on this comparison, the efficiency of polymer in inhibition the corrosion process was calculated for different concentrations of polymer. A general reduction in corrosion of mild steel was observed with the use of polymer solutions irrespective of the concentration used.

For the deionized water environment, a very high corrosion rate was observed in the first 72 hours of exposure, but subsequently, the corrosion rate reduced and did not significantly change with contact time. The addition of xanthan gum polymer of varied concentrations (1.0, 1, 3, and 5 wt.%) however generally reduced the corrosion rates. This shows that addition of xanthan gum to water can reduce the corrosion rate of mild steel at any concentration like the investigated concentrations. Furthermore, the corrosion rates of mild steel did not significantly increase with exposure time with the addition of xanthan gum of varied concentrations to the solution except for 5 wt.% concentration that shows an initial low corrosion that later increased slightly with increased contact time. The efficiency of the polymer in reducing the corrosion rate of mild steel is generally above 50% with the best efficiency been observed with the use of 3% concentration.

Figure 2 presents the results of the sets of tests in which the mild steel coupons were exposed to 10% formation brine environment with and without xanthan gum polymer concentration addition. The mild steel exposed to 10% formation brine without polymer had the highest corrosion rate (0.0126-0.0165 mg/cm^2.h) relative to that of xanthan gum solutions. The corrosion rate started slowly and increased with an increase in exposure time until it became relatively stable. The addition of xanthan gum to the brine generally reduced the corrosion rate of mild steel irrespective of the concentration of the polymer in the brine. The lowest concentration of xanthan gum (0.5 wt.%) generated lower corrosion inhibition with efficiencies of 42-86%. Increase in the concentration of polymer resulted in increase in corrosion inhibition with efficiencies of 70% and above. It is however observed that there was no significant effect of varied concentrations of xanthan gum on the corrosion inhibition hence, a higher concentration of xanthan gum is not required to reduce the corrosion rate in this saline environment. This also shows that the enhanced oil recovery application of this polymer at different concentrations investigated in 10% formation brine has the potential to reduce the corrosion rate in addition to improving oil recovery.

The results of the set of tests in which the mild steel coupons were exposed to 50% formation brine environments with and without xanthan gum addition are presented in Figure 3. Higher corrosion rate was observed with the use of the brine alone without xanthan gum relative to polymer solutions. An initial high corrosion rate of 0.0191 mg/cm^2.h was observed within 72 hours of exposure of mild steel to the brine without polymer, it then reduced to 0.0117 mg/cm^2.h within another 72 hours before increasing to 0.0177 mg/cm^2.h and then reduced to 0.0150 mg/cm^2.h. Similar to the previous results, the addition of xanthan gum of varied concentrations to the brine resulted in the reduction of corrosion rates of mild steel. The efficiencies (< 70%) of the corrosion inhibition in this saline environment are however lower than that of the 10% formation brine. In respect to the effect of varied concentrations of xanthan gum on corrosion inhibition, a better reduction in corrosion rate was observed with increase in its concentration. This suggests that the concentration of xanthan gum in this environment may influence its effect on the corrosion inhibition process.

Figure 4 presents the results of the set of tests in which the mild steel coupons were exposed to 100% formation brine environments with and without xanthan gum addition. The results followed similar trends observed from the previous tests in which higher corrosion rates were observed in brines without polymer when compared with the same brine with xanthan gum of different concentrations. A slight increase in corrosion rate was observed with an increase in exposure time in 100% formation brine. This trend was also observed with the addition of varied concentrations of xanthan gum except for 1% concentration which show a decrease in corrosion rate with an increase in exposure time. Generally, a decrease in corrosion rates was observed with the addition of xanthan gum to the brine irrespective of concentration. The efficiencies of the different concentrations of xanthan gum in inhibiting corrosion rates were found to be above 50%. This further shows that the enhanced oil recovery application of this polymer may be associated with a reduced corrosion rate.

For a better understanding of the corrosion inhibition of xanthan gum in varied saline environments. The corrosion rates were related to salinities of the saline environments and the varied concentrations of xanthan gum, and the results are presented in Figure 5. Generally, lower corrosion rates were observed with the use of xanthan gum of varied concentrations relative to all the solutions without xanthan gum (Figure 5a). There was however no significant effect of salinity variation seen on the corrosion rate of mild steel. This shows that the level of salinity in the environment is not a dominant factor in the observed corrosion inhibition. This is consistent with the fact that xanthan gum is not sensitive to salinity because its presence in a saline environment enhances intermolecular interactions between its chains and results in an increase in its aggregation [21]. From Figure 5b, it is obvious that the concentration of xanthan gum in saline environments is a dominant factor in the observed corrosion inhibition in different saline environments.

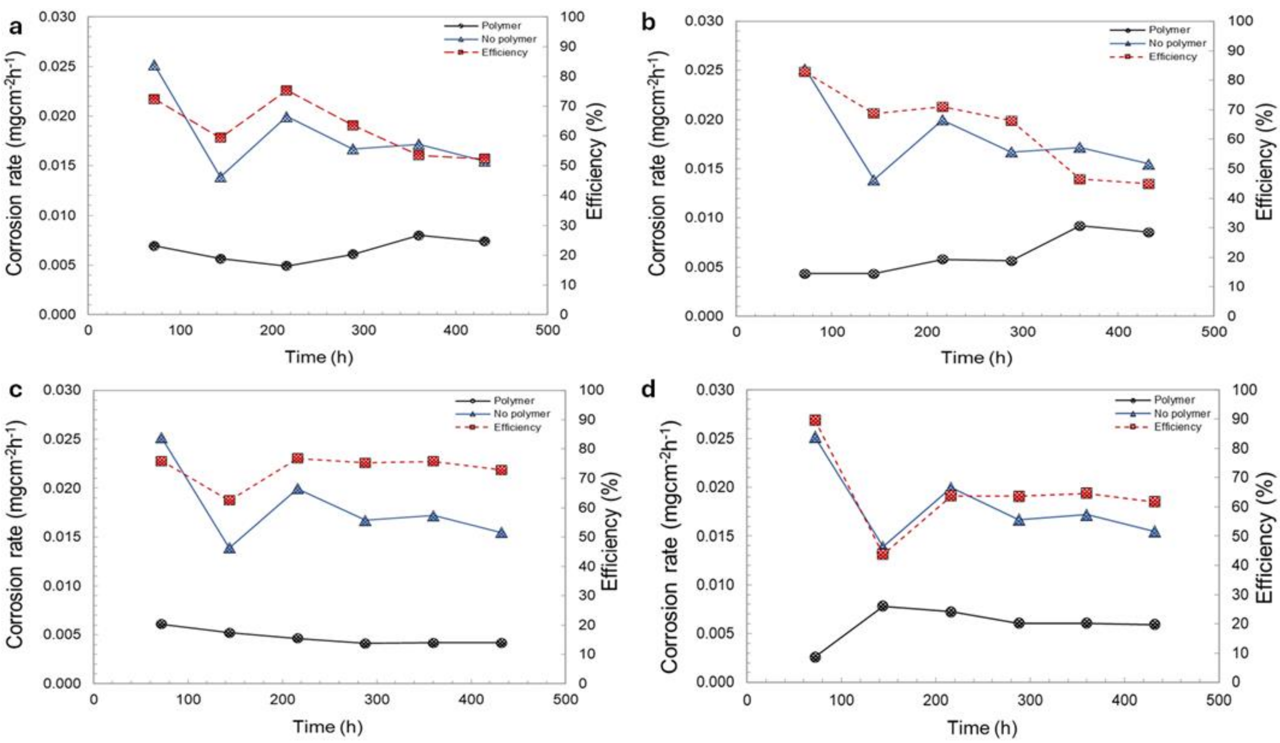

Figure 1 The corrosion rate of mild steel immersed in 10% saline environment with and without xanthan gum and the efficiencies of xanthan gum corrosion inhibition for (a) 0.5 wt.% concentration, (b) 1 wt.% concentration, (c) 3 wt.% concentration and (d) 5 wt.% concentration

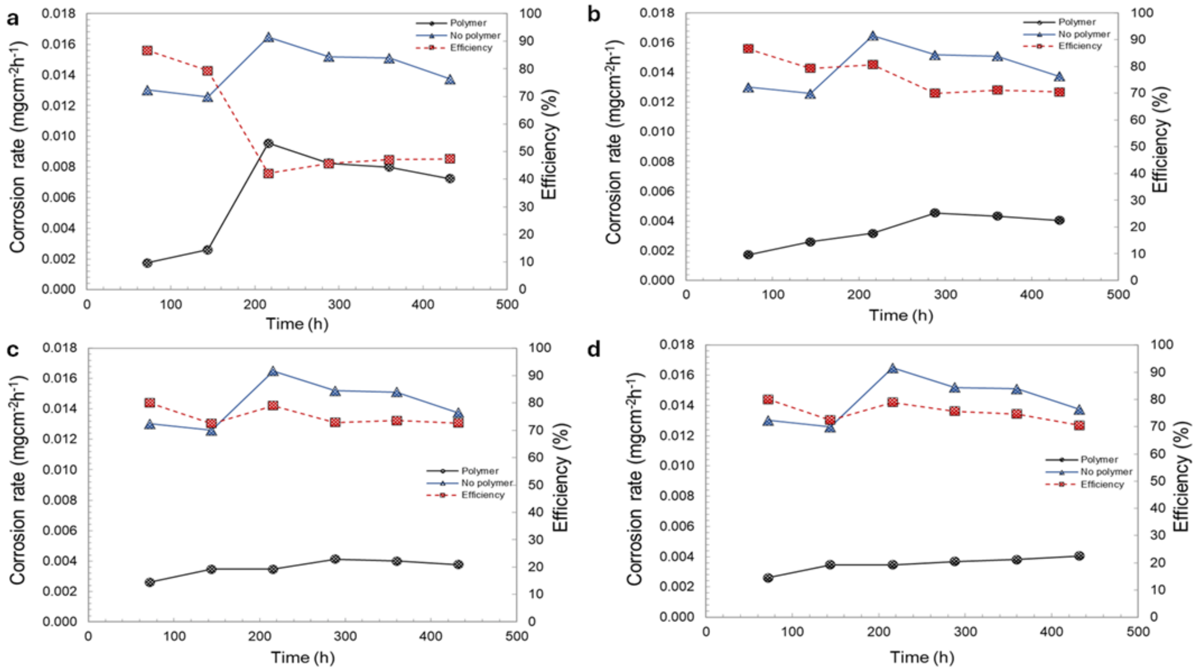

Figure 2 The corrosion rate of mild steel immersed in 0% saline (deionized water) environment with and without xanthan gum and the efficiencies of xanthan gum corrosion modifications for (a) 0.5 wt.% concentration, (b) 1 wt.% concentration, (c) 3 wt.% concentration and (d) 5 wt.% concentration.

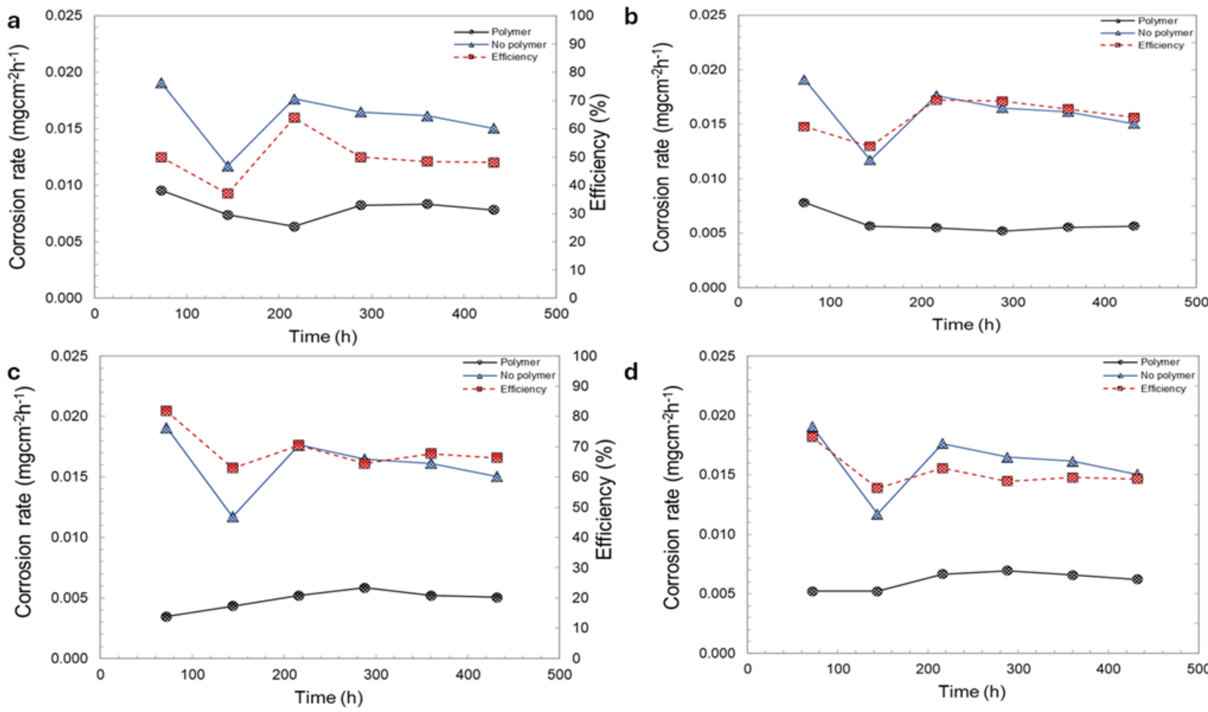

Figure 3 The corrosion rate of mild steel immersed in 50% saline (deionized water) environment with and without xanthan gum and the efficiencies of xanthan gum corrosion inhibition for (a) 0.5 wt.% concentration, (b) 1 wt.% concentration, (c) 3 wt.% concentration and (d) 5 wt.% concentration.

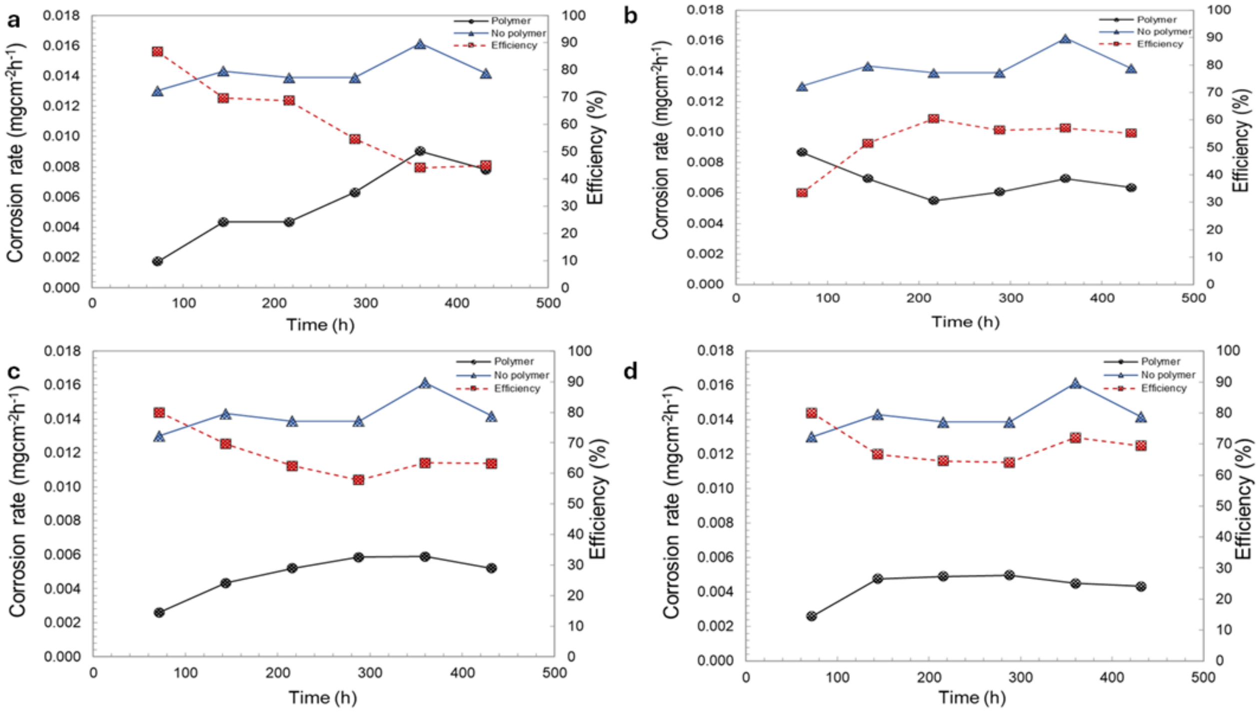

Figure 4 The corrosion rate of mild steel immersed in 100% saline (deionized water) environment with and without xanthan gum and the efficiencies of xanthan gum corrosion inhibition for (a) 0.5 wt.% concentration, (b) 1 wt.% concentration, (c) 3 wt.% concentration and (d) 5 wt.% concentration.

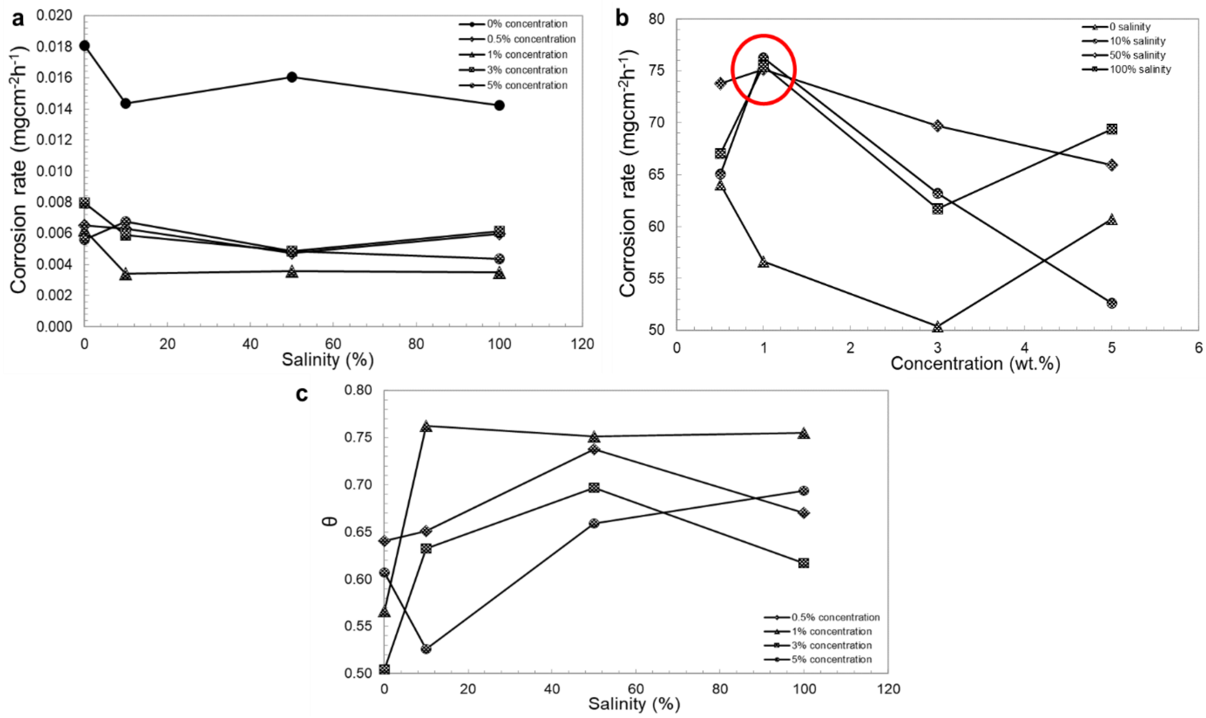

Figure 5 The comparison analysis of (a) the effect of varied saline environments on corrosion rates, (b) the effect of varied concentrations of xanthan gum on corrosion rates, and (c) the effect of varied saline environments on surface coverage of xanthan gum.

In all saline environments, the highest corrosion inhibition efficiency was observed at 1 wt.% concentration of xanthan gum as indicated by the red circle in Figure 5b. This shows that the application of xanthan gum in an enhanced oil recovery process at the concentrations investigated in this study will not only improve oil recovery but also preserve the flowline by inhibiting its corrosion.

Relating the surface coverage of xanthan gum to the salinity of the environments as shown in Figure 5c, it can be seen that at 1 wt.% concentration, there was high coverage of xanthan gum on the surface of the mild steel thereby limiting the interactions between the metal and its environments. The mechanism by which polymers inhibit corrosion is interfacial adsorption that results in the formation of a protective film on the metal surface thereby preventing the components of the aqueous phase from adsorbing on the surface of the metal matrix [22]. From all the tests, it is obvious that the addition of xanthan gum polymer to all the solutions reduced the corrosion rates of mild steel irrespective of the concentration of polymer and salinity of the saline environments. This is attributable to the structural composition of xanthan gum. Previous studies have shown that xanthan gum has good resistance to temperature, pH, and salinity although it is said that precipitation can occur when multivalent cations are present in the brine [21]. This explains the effectiveness of xanthan gum in reducing the corrosion rates in different saline environments. The results of this study show that the enhanced oil recovery application of this polymer might serve a dual purpose of improving oil recovery through mobility control and preservation the flowline through which it flows.

Conclusions

1. This study investigated the possible effects of the use of environmentally friendly polymer (xanthan gum) of varied concentrations on the corrosion rates of mild steel in different saline environments.

2. The results of the study showed that corrosion of mild steel increases with an increase in its contact time in all environments investigated.

3. The addition of xanthan gum polymer of varied concentrations to all the different environments investigated reduced the corrosion rate irrespective of the salinity and concentration of the environments.

4. The results of this study show that the enhanced oil recovery application of xanthan gum has the potential to serve a dual purpose of improving oil recovery through mobility control and preservation of the flowline through corrosion inhibition.

Funding sources

Not applicable.

Conflicts of interest

No conflict of interest

Abbreviations

EOR: Enhanced oil recovery

CR: Corrosion rate of polymer

E: Efficiency of polymer

θ: Surface coverage of polymer

CR_0: Corrosion rate without polymer

W: Difference in initial and final weights of metal coupons

A: Area of metal coupons

t: Time of immersion of metal coupons in solutions

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