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DEVELOPMENT AND EVALUATION OF DUAL FUNCTION SCALE AND CORROSION INHIBITOR

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ABSTRACT

Corrosion and scaling are two common and major problems encountered in water treatment systems. In this study, we have investigated the dual behavior of a maleic acid based copolymer on scale and corrosion inhibition for solving both the problems together. Two different types of maleic acid – ortho toluidine (MA-OT) copolymer were synthesized by varying the proportion of monomers and characterized by FTIR spectroscopy. The anti-scaling properties of the polymer towards $CaCO_3$ scale were studied through chemical and electrochemical screening tests at different pH, temperature and inhibitor concentration. The corrosion inhibition performance of the copolymer was tested through weight loss method and through optical and scanning electron microscopes. The effect of copolymer on the calcite scale crystal morphology and structures were examined through SEM. Statistical methods such as analysis of variance (ANOVA) and response surface methodology were used to analyze the data and model the performance of the dual inhibitor.

Keywords: Corrosion, scale inhibitor, calcite, dual inhibitor, maleic acid, copolymer, flow assurance.

INTRODUCTION

The handling of crude oil and the routine problems of corrosion and scale are a major concern for oil companies worldwide. The variety and complexity of the fluids transported from the producing formation to the customer add to the difficulty of providing adequate methods of treatment to alleviate these problems. Each year oil companies spend millions of dollars to protect their investment in equipment and production while some of the highest costs are incurred in the prevention of corrosion and scale. Fluid flow restrictions resulting in increased pressure and therefore greater probability of conduit failure are also a major concern of petroleum industry (Malcolm, 2014; Olajire, 2015). Organic constrictions (paraffin and asphaltene) and inorganic constrictions (scale and silicate fines) can be as much a source of problems as corrosion.

Corrosion and scale formation are typically interlinked phenomena. In most cases corrosion products such as iron sulfide and iron carbonate induce scale deposition on the metal surfaces. Scale deposits can also cause rapid localized corrosion and subsequent penetration of metallic surfaces through the formation of differential oxygen concentration cells. The localized corrosion resulting from differential oxygen cells originating from deposits is commonly referred to as under deposit corrosion. Hence these two phenomena work together leading to loss of metal.

Generally, the high cost of special alloys which offer a high resistance to the process of corrosion, precludes their use. Consequently, other means of protection are necessary. The petroleum companies usually employ several forms of protection ranging from electrolytic (cathodic protection) to chemical surface passivation. Chemical means have been the most widely used and easiest method of corrosion protection treatment in industry. The majority of time, the oil field application of corrosion control chemicals involves continuous and batch treatments. Continuous treatment requires a capillary string, while batch treatment involves the periodic pumping of chemicals. Corrosion inhibitor chemicals are adsorbed at actively corroding sites on the metal surfaces, interfere with the processes of electronationand de-electronation.

The inhibition of corrosion of aluminum pigments in alkaline media by homopolymers of (methyl) acrylic acid and copolymers of acrylic and maleic acid has been studied. Acrylic acid-acrylonitrile and methacrylic acid-acrylonitrile copolymers were used as antiscalants and they showed very good antiscaling performance at lower temperatures and pHs but at higher pH and temperatures

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*Corresponding author e-mail: dr.senthilmurugan@yahoo.com they act as flocculants (Cenergy *et al*., 1991). Copolymers of maleic acid, acrylic acid and acrylamide have been shown to exhibit good antiscaling properties at high temperatures (Senthilmurugan *et al*., 2010; Li *et al*., 2017). Simultaneous control of scale and corrosion can be accomplished using combined inhibitors (combination of scale and corrosion inhibitors) effectively (Sanders *et al*., 2014). Multifunctional production chemicals (single product with multiple functionalities) offer several advantages related to cost savings, inventory, equipment usage and environmental impact (Collins *et al*., 2001). The present study deals with developing an integrated corrosion and scale inhibitor according to the principles that both the problems are inter connected and need to be solved simultaneously in most of the industrial environment. The scale inhibition efficiency of a 50:50 copolymer of maleic acid – ortho toluidine (MA-OT) had been studied earlier (Senthilmurugan *et al*., 2011). In this study, MA-OT copolymers are synthesized with different monomer compositions. The copolymers are characterized and evaluated for their corrosion and scale inhibition performance. The effect of variation in monomer composition on the scale and corrosion inhibition property of the copolymer is also investigated.

MATERIALS AND METHODS

Experimental procedure

Maleic acid – ortho toluidine (MA-OT) copolymers were synthesized with two different compositions. The copolymers were characterized using GPC and FTIR. Antiscaling efficiency was determined using static jar tests and electrochemical studies. Scale morphology of treated and untreated solutions was studied using scanning electron microscope. The corrosion inhibition property of the copolymer was tested through weight loss method and inhibition property revealed through morphological study conducted on the treated metal surface by SEM and optical digital microscopy.

Synthesis of MA-OT Copolymers

The two types of maleic acid (HOOCHC=CHCOOH) and orthotoluidine(o-methylaniline, $CH_3C_6H_4NH_2$) copolymers were prepared in an aqueous medium through free radical polymerization by changing the monomer mole ratio at (60:40) and (40:60). The polymerization reaction was carried out in an inert atmosphere to remove molecular oxygen, which will otherwise inactivate the initiator. Nitrogen gas, which was purified by removing traces of oxygen, was passed through the solution to create the inert atmosphere. This purification was done by passing nitrogen gas through Fisher solution, saturated lead acetate and distilled water in sequence (Salamone, 1999). Potassium peroxodisulphate was used as the initiator for polymerization.

Diluted monomer solutions were taken for polymerization. Undiluted monomers and concentrated solution of monomers are not recommended, as the heat of polymerization makes it difficult to control the process, which would result in hazardous conditions. In addition, the resulting polymer is often insoluble (Cenergy *et al*., 1991). The copolymer is prepared by varying monomer ratios (60:40 and 40:60) through diluted monomers of maleic acid and ortho toluidine.

Characterization of copolymers

Gel permeation chromatography (GPC) is a form of liquid chromatography technique, which is extensively used for molecular size determination. This mode of chromatography separates the molecules according to their molecular size, which can be related to their molecular weights. The high molecular weight component elutes first, followed by low molecular weight components. The technique is the method of choice for the separation of a mixture containing components with molecular weight difference of at least 10%. A porous gel of controlled/defined pore size is used as column packing. Molecules which are bigger than the pore of gel are excluded and elute along with the solvent front, whereas the molecules of smaller size permeate into the pores and by the diffusion process are eluted at different time intervals.

The equipment used for GPC analysis is model 515, Waters HPLC, Austria. Column material: poly styrene - divinylbenzene copolymer. Column size: 100A°, 60 cm x 7.8 mm, Mobile phase: sodium azide solution, Detector: Refractive Index (RI) waters 2410.

The synthesized polymers were examined through FTIR spectral studies to confirm the presence of functional groups that are responsible for antiscaling property. The FT-IR spectrum was taken for the polymer by using FTIR spectrometer, Perkin Elmer Paragon, model-500, in pressed KBr cells.

Autoclave Jar Test

The chemical screening tests were carried out to evaluate the copolymers in autoclave system for stimulating high temperature reservoir environment. NACE standard TM0374-95 was followed to conduct static jar tests for quantifying scale inhibiting properties of the co-polymers (NACE, 2016). The tests were carried out at 120°C in the pH range of 7.0 to 8.5. Ca^{2+} (cationic) brine and CO_3^{2-} (anionic) brines were prepared separately to meet stoichiometric proportion of 1200ppm each and CO_2 was bubbled through both the brines just before mixing. In all cases, 50:50 ratios of the two solutions were maintained.

Scale inhibitor was mixed with anionic solution in predetermined concentration and the cells were placed in a shaker water bath at a constant temperature for 24 hours. The cells were allowed to cool without disturbance for 3 hours. The supernatant solutions from the jars were collected and the residual calcium ion in the solution was determined using EDTA titration. The tests were repeated for different levels of pH and inhibitor dosages. Scale inhibitor efficiency was calculated based on remaining Ca^{2+} ions in solution using the following equation.

$$\% \text{ Scale Inhibition Efficiency} = 100\ \frac{C_a - C_b}{C_c - C_b} \qquad (1)$$

Where:
C_a = Concentration of Ca^{2+} ion in the treated solution after precipitation
C_b = Concentration of Ca^{2+} ion in the blank solution after precipitation
C_c = Concentration of Ca^{2+} ion in the blank solution before precipitation

Constant Potential Electrolysis for Scale Study

The instrument EG&G Princeton Applied Research (PAR) Versa Statpotentiostat - galvanostat instrument was used for study of polymers. The three-electrode cell assembly was used. The working and counter – electrodes were of platinum foils of area 1cm x 1cm. A saturated calomel electrode (SCE) was used as the reference electrode. The calcium bicarbonate brine 300ppm sample was taken for this study, by using various dosage levels of the antiscalants. The test was carried out by applying a constant potential of –1.2V vs SCE to the working electrode dipped in the solution for 30 minutes at room temperature and the change in current density with time was recorded. The working platinum electrode was cleaned by using fuming nitric acid and repeatedly washed with double distilled water after each experiment.

Weight loss method for corrosion study

NACE/ASTM test method TM0169 was used to study the corrosion inhibition performance of the copolymer on mild steel surfaces (NACE, 2012). Brine water composition of 600ppm hardness (450ppm of Ca^{2+} ions and 150 ppm of Mg^{2+} ions) was used for the study. Mild steel N80 grade specimens were adopted for this weight loss study.

Pre weighed mild steel specimen of area 12.5 sq.cm were immersed in test solution with varying concentration of inhibitors, along with control, for a period 168 hour at 70^{o}C temperature. After the exposure time, the steel coupons were removed, cleaned and weighed to determine the weight differences. The loss of weight of the coupons was converted into rate of corrosion in 'mdd' units (milligrams of metal lost per square decimeter per day) for blank and inhibited solutions.

Morphological Study

The scale inhibition by modification of the calcium carbonate crystals on metals upon adding the polymeric antiscalants was confirmed by studying the surface morphology of the metal specimens. The crystal formation on the metal surface after exposing them to the test conditions was analyzed by using JOEL JSM 840A Scanning electron microscopy. For making the surface conductive a fine gold coating was given by using JFC100E ion sputtering device.

The surface morphology of the mild steel specimens exposed to the brine water medium without and with corrosion inhibitors at their best concentration were studied by using model Hirox (KH7700 series) digital optical microscope.

Statistical Analysis

The results from scale inhibition efficiency measurements from static jar tests are analyzed using statistical methods such as analysis of variance (ANOVA) and response surface methodology (RSM). The ranges for the independent parameters (denoted by x_1 and x_2) were 7 to 8.5 for pH and 1 to 30ppm for inhibitor concentration. The scale inhibition efficiency, denoted by Y, was the dependent response. The experimental data was fitted into a transfer function to capture the linear and interaction effects of the parameters. The coefficients of the transfer function were determined using method of least squares. The numerical magnitude of the coefficients could be used to gauge the importance of each parameter in affecting the response variable. The linear and the quadratic effects of the factors were studied and the interaction on the responses were obtained using analyses of variance (ANOVA). All statistical analyses were performed using the software Design Expert 11 (Stat-Ease).

RESULTS AND DISCUSSION

Maleic acid - Ortho toluidine (MA-OT) co-polymers were synthesized by varying monomer ratio in aqueous medium through free radical polymerization by using an initiator. The two different types of MA-OT copolymer were prepared by blending different ratio of the monomer such as 60:40 and 40:60 to test the inhibition character of the copolymer on scale and corrosion simultaneously. The molecular weight and molecular weight distribution of the polymeric antiscalants were determined through gel permeation chromatography (GPC). The copolymer having a molecular weight of about 15000 and narrow molecular weight distribution were selected from the group of polymers prepared for further tests. Thermal stability of MA-OT copolymer has been studied earlier at higher temperatures through DSC and TGA experiments where the copolymer was found to be stable at high temperatures up to 140°C (Senthilmurugan *et al*., 2011).

Functional group identification through FTIR studies

The compositions of the resulting copolymer were determined by FTIR. During the FTIR study same type of IR spectrum was observed for both the monomer ratio altered copolymers, it may be due to same functional group present in both the copolymers. The FTIR spectrum in Figure 1 shows the peaks of MA-OT (Aromatic CH_3 Vibration, 2927 cm^{-1}; C=O Stretch of carbonyl group, 1710 cm^{-1}; C-COOH Asymmetric stretching vibration, 1636 cm^{-1}; N-H bending, 1586 cm^{-1}; Combination band of C-O stretching & O-H in plane deformation vibration, 1391 cm^{-1}; C-N and skeletal stretching, 1274 cm^{-1}). Hence, it is confirmed that the FTIR spectrum corresponds to the structure of MA-OT. The possible structures of maleic acid-ortho toluidine copolymer are given in Figure 2.

Performance evaluation of copolymers on scale inhibition

Table 1 represents the static jar test results of both the co-polymers at $120^{o}C$ at pH from 7.0 to 8.5. The results show that inhibition efficiency of the polymers is both temperature and pH dependent. MA-OT (60:40), 30ppm dosage of copolymer shows 100% scale inhibition at pH 7.0 at 120°C. In case of MA-OT (40:60) copolymer inhibition efficiency reduced by 20% as compared to MA-OT (60:40), this may be due to the smaller number of free inhibiting functional groups present in this polymer. Dosage requirement is slightly higher for achieving 100% efficiency at higher pH. MA-OT (60:40) copolymer shows higher scale inhibition efficiency than MA-OT (40:60) ratio copolymer, which may be due to more number of free carboxylic groups present in 60:40 ratio than 40:60, which is the group more responsible for scale inhibition.

Statistical analysis of scale inhibition efficiency

The results from the static jar tests (Table 1) were analyzed using response surface methodology. Preliminary analysis of the data shows that inhibition efficiency varies directly with inhibitor concentration and inversely with pH. The regression coefficient (R squared) value was greater than 0.96 for both data sets indicating an excellent fit of the model to the data. Significant factors and interaction terms were selected based on the p-value. For a 95% confidence level, a factor significantly affects the outcome if the p-value is less than 0.05. Anova was performed in steps by eliminating the terms that have a p-value greater than 0.05, to improve the accuracy of the model. The overall p-value of the model was less than 0.001 which shows that the fitted model is statistically significant. The linear effects of pH and concentration were found to be most significant followed by the interaction effects. The transfer functions fitted to the data for 60:40 and 40:60 inhibitors are given below.

$$Y = 82.7 - 5.46X_1 + 2.80X_2 - 0.07X_1X_2 - 0.01X_2^2 \qquad \ldots(2)$$

$$Y = 86.5 - 6.69X_1 + 1.29X_2 \qquad \ldots(3)$$

Where Y is the predicted scale inhibition efficiency, X_1 is pH and X_2 is inhibitor concentration. A positive linear coefficient indicates that the parameter has a direct effect on the inhibition efficiency and a negative coefficient indicates that the parameter has an inverse effect. It can be seen that the inhibition efficiency increases with increase in copolymer concentration whereas it decreases with increase in pH.

The response surface of the inhibition efficiency is plotted against two operating variables for both cases. The 3D plots (Figs. 3 and 4) were obtained by using the above equations and shows the effect of the pH and temperature on the inhibition efficiency. In case of 40:60 copolymer, the linear model provided the best fit and the interaction and quadratic terms were found to be insignificant. The pH has a linear effect in all the range studied (50 - 70°C). The effect of concentration is slightly non-linear for 60:40 case due to presence of quadratic and interaction terms. The above models could be used to select the appropriate combination of operating parameters to obtain optimum scale inhibition efficiency.

Constant potential electrolysis technique for evaluating scale inhibition

This electrochemical technique which is often referred as chronoamperometry in literature is presently termed as constant potential electrolysis in the present studies as the time measurement is in the order of several seconds, which is not characteristic of transient technique where the diffusion from bulk to the electrode surface is excluded. In the measurement, for time running into several seconds diffusion of oxygen from the bulk to the electrode is quite possible and hence we will presently name the technique as constant potential electrolysis rather than the chrono technique (Deslouis *et al*., 1997; Simpson, 1998).

The constant potential electrolysis results are tabulated for both copolymers in Tables 2, 3 and Figures 5 and 6. The scaling time (t) is defined as the time required for the full coverage of the electrode surface with the insulating scale (Deslouis *et al*., 1997). The residual current (I_R) and scaling time was calculated for the control as 32.05 μA and 650 sec, respectively. The residual current and scaling time values are found to increase with the addition of polymer compared to that in the control. In Figure 5, the scaling time of MA-OT (60:40) copolymer shows 1900 sec for 20ppm dosage and this result is in good agreement with autoclave jar test. In case of MA-OT (40:60) at 20ppm, the scaling time was 1700 sec. An increase in scaling time indicates better scale inhibition performance. With the polymer addition, there is no formation of scale, and the oxygen reduction proceeds uninterruptedly on the catalytic metal surface leading to higher residual current and more scaling observed (Simpson, 1998).

Weight loss method for evaluating corrosion inhibition property

In the oilfield, the types of metal employed in equipment are numerous, but because of the cost versus performance properties of mild steel, it is the most commonly used. Weight loss is probably the most common form of measurement of corrosion control effectiveness (NACE, 2012). The tests were carried out in 600ppm hardness brine solution environment at 70°C temperature to represent vigorous field conditions.

The weight loss method results obtained for both the copolymers are shown in Tables 4 and 5. In both cases, the corrosion inhibition efficiency increases with increase in copolymer concentration. This is possibly due to inhibitor increasing the coverage of metal surface by forming a film on metal surfaces that stops the flow of corrosion current. MA-OT (40:60) copolymer shows 90.5% corrosion inhibition efficiency at 30ppm dosage. In case of MA-OT (60:40), inhibition efficiency was observed to be 80.90% at 30 ppm dosage. The corrosion rate in weight loss drastically decreases from control value of 146.3mdd in both the cases. MA-OT (40:60) copolymer gives higher corrosion inhibition efficiency than MA-OT (60:40), which could be due to presence of more number of strong cationic charges holding nitrogen in the copolymer and chemically absorbed in the anodic sites on the metal surface. The amine group in the polymer is responsible for corrosion inhibition whereas the carboxylic group is required for scale inhibition. Hence, depending on the relative severity of these two problems, the respective concentrations of the two monomers can be adjusted to produce the copolymer for optimum performance.

Morphological study for scale and corrosion

SEM images of un-inhibited and fully inhibited $CaCO_3$ crystals are shown in Figures 7a, 7b and 7c. The cubic shaped blocks like crystals in Figure 7a are typical of calcite structure (Nancollas *et al*., 1982; Sawada *et al*., 1990). In Figures 7b and 7c, the modified crystal structure of calcite can be observed where the crystals are in irregular oval shape. In Figure 7c, the scale growing active sites are fully blocked indicating a higher scale inhibition for MA-OT 60:40 copolymer. Due to change of crystal morphology of calcites from regular cubical shape to irregular spherical shape of different sizes, stacking of cubes and their further growth in size is inhibited which reduced or prevented the scale to be deposited on the surface (Wada, 1995).

The obtained optical microscopic and SEM images are placed in Figures 8 and 9 for corrosion morphology study. Both the optical and SEM micrographs showed severe corrosion of the steel surface in blank case (Figs. 8a and 9a). The metal surface exposed to MA-OT copolymer solution are not much corroded due to the thin film layer formed on metal surface which protected from the corrosion. MA-OT 40:60 (Figs. 8c and 9c) treated surface shows less corrosion compared to MA-OT 60:40 (Figs. 8b and 9b), which is in concurrence with the results from weight loss measurements. SEM and optical microscopic images confirmed the dual behavior of inhibition property of MA-OT copolymer on scale and corrosion.

CONCLUSION

Mitigation of scale and corrosion is a great challenge for industry because these two problems mostly occur simultaneously and hence it is necessary to solve both the problems together. Maleic acid – orthotoluidine copolymer exhibited good performance on scale and corrosion inhibition simultaneously. Copolymers were synthesized with two different monomer ratios. The copolymers were characterized through GPC and FTIR studies. The copolymers showed good scale inhibition efficiency even at very high temperature (120°C) and higher pH (8.5). Complete scale inhibition could be achieved by increasing the inhibitor dosage. Evaluation of the scale inhibition property was done through static jar tests and the results were found to be in good agreement with constant potential electrolysis. Corrosion inhibition property was evaluated through weight loss method and the results were matching with optical microscopic images. SEM and optical microscopic studies show the difference of un-inhibited and inhibited crystal morphology and gives the idea about mechanism of scale and corrosion inhibition.

The dual behavior of maleic acid - ortho toluidine copolymer helps to solve the scale and corrosion problem together in industry. It was observed that the relative concentrations of the functional groups - carboxylic acid (from maleic acid monomer) and amine (from o-toluidine monomer) yields customizable scale inhibition and corrosion inhibition performance. This unique property can be used to optimize scale and corrosion mitigation in the field using a single inhibitor based on the severity of the field condition. Other functional groups can also be added to the copolymer backbone to impart different properties like antimicrobial activity to yield a valuable multifunctional inhibitor.

Table 1. Scale inhibition efficiency of MA – OT copolymer on calcium carbonate (600ppm Ca^{2+}) scale at 120°C through autoclave jar test.

Dosage	Inhibitor efficiency (%) at different pH							
	MA-OT (60:40)				MA-OT (40:60)			
	7.0	**7.5**	**8.0**	**8.5**	**7.0**	**7.5**	**8.0**	**8.5**
1 ppm	47	45	44	41	40	37	36	34
5 ppm	55	52	48	45	45	43	40	37
10 ppm	65	61	58	55	52	48	44	41
15 ppm	77	72	67	64	62	55	50	49
20 ppm	86	84	81	77	67	64	61	58
25 ppm	95	91	88	86	73	64	59	57
30 ppm	100	96	92	88	79	77	74	72

Table 2. Scaling time and residual current for calcium carbonate scaling (300ppm Ca^{2+}) from constant potential electrolysis at pH 8.0 with different dosage levels of MA-OT (60:40) copolymer.

Test	Dosage Level (ppm)	Residual Current (μA)	Scaling Time (s)
1	Blank	32.05	650
2	5	95.02	920
3	10	131.65	1090
4	20	230.96	1900

Table 3. Scaling time and residual current for calcium carbonate scaling (300ppm Ca^{2+}) from constant potential electrolysis at pH 8.0 with different dosage levels of MA-OT (40:60) copolymer.

Test	Dosage Level (ppm)	Residual Current (μA)	Scaling Time (s)
1	Blank	32.05	650
2	5	83.02	930
3	10	109.56	1240
4	20	165.78	1700

Table 4. Corrosion parameters of mild steel in 600ppm Ca^{2+} ion solution at different concentrations of MA-OT (40:60) inhibitor at 70^{o}C by weight loss method.

Inhibitor Concentration (ppm)	Corrosion rate (mdd)[a]	Equivalent corrosion current (A/cm^2)	Inhibition efficiency (%)
Blank	146.3	4.33 x 10^{-5}	-
5	72.95	2.22 x 10^{-5}	50.1
10	70.10	2.14 x 10^{-5}	52.1
20	36.94	1.11 x 10^{-5}	74.8
30	13.99	4.20 x 10^{-6}	90.5

[a] milligrams of metal lost per square decimeter per day

Table 5. Corrosion parameters of mild steel in 600ppm Ca^{2+} ionsolution at different concentrations of MA-OT (60:40) inhibitor at 70^{o}C by weight loss method.

Inhibitor Concentration (ppm)	Corrosion rate (mdd)	Equivalent corrosion current (A/cm^2)	Inhibition efficiency (%)
Blank	146.3	4.33 x 10^{-5}	-
5	89.93	2.82 x 10^{-5}	38.50
10	51.20	1.55 x 10^{-6}	65.00
20	44.10	1.29 x 10^{-5}	69.86
30	27.95	8.29 x 10^{-6}	80.90

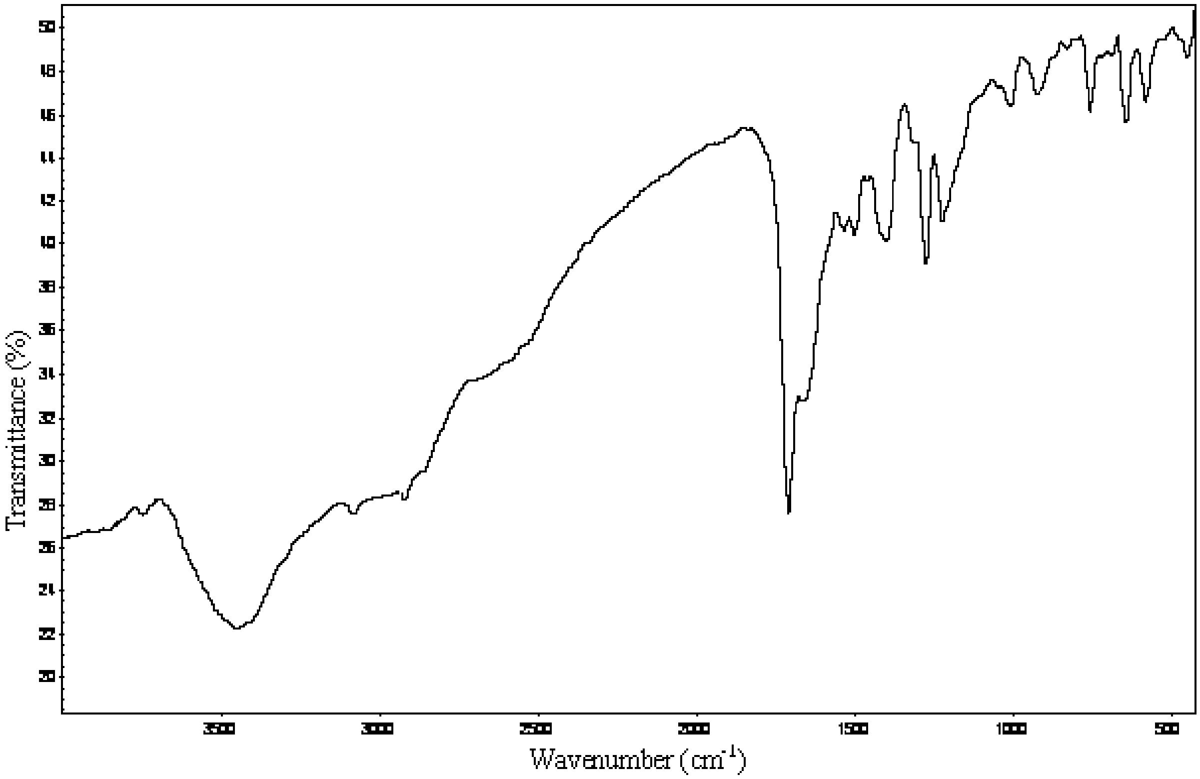

Fig. 1. Fourier transform infrared spectra of synthesized MA-OT co-polymer.

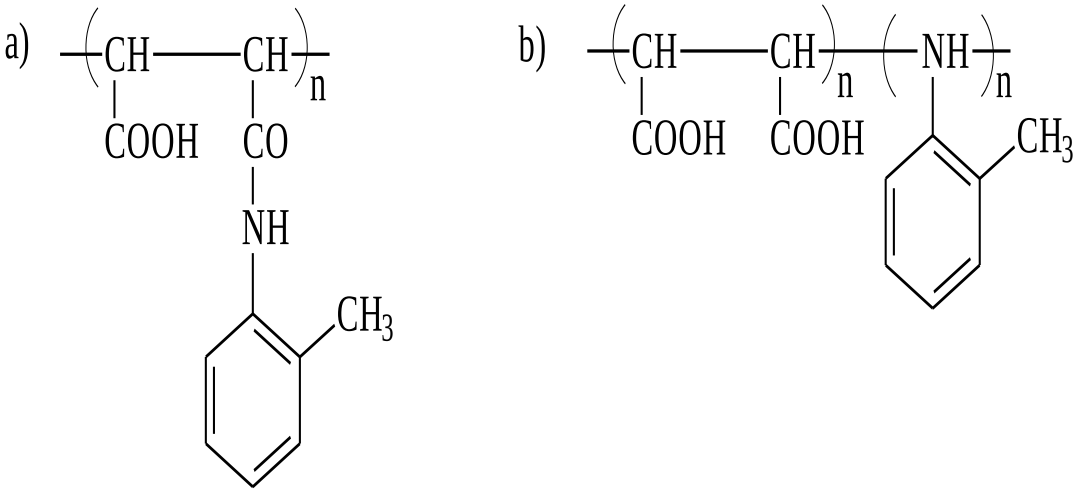

Fig. 2. Structure of maleic acid – ortho toluidine (MA-OT) copolymer.

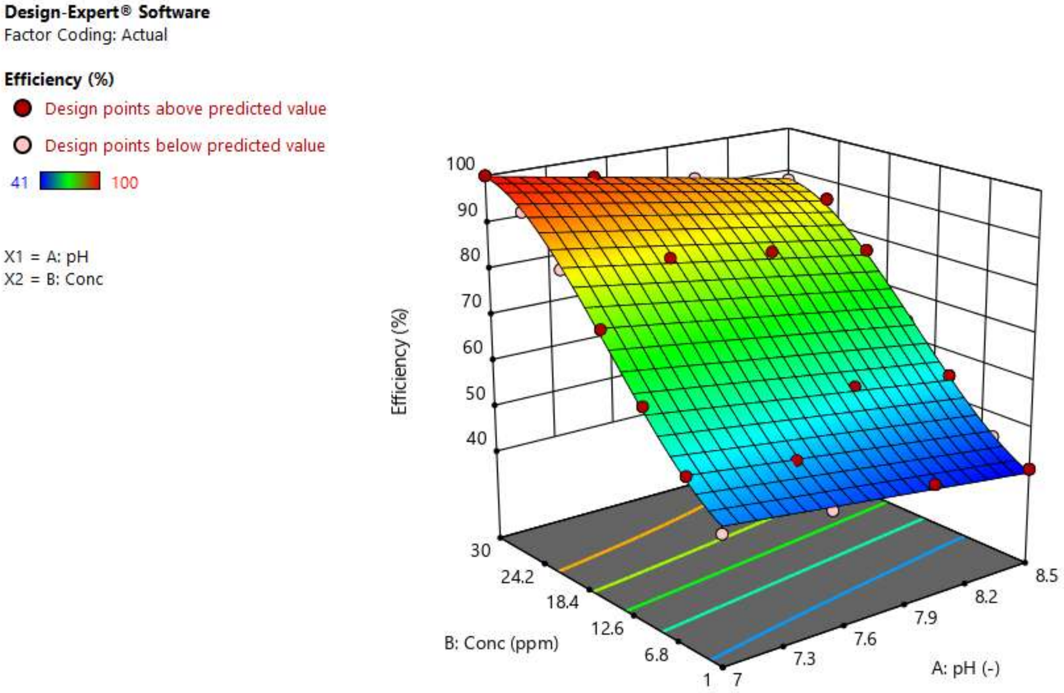

Fig. 3. Response surface plot of scale inhibition efficiency of 60:40 MA-OT copolymer as a function of pH and inhibitor concentration.

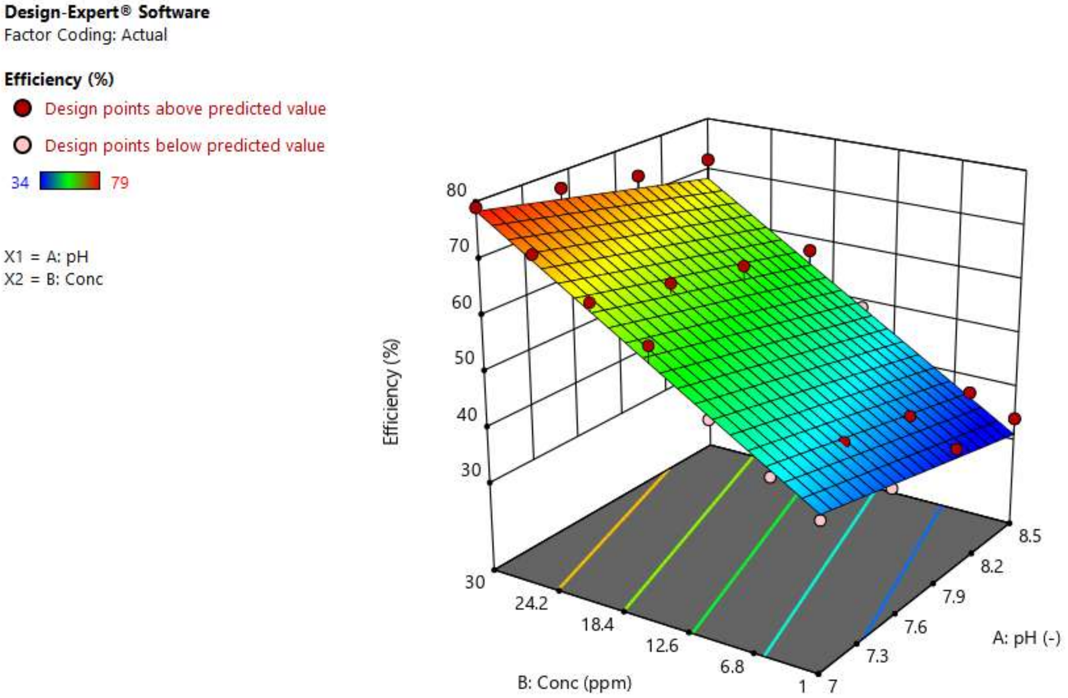

Fig. 4. Response surface plot of scale inhibition efficiency of 40:60 MA-OT copolymer as a function of pH and inhibitor concentration.

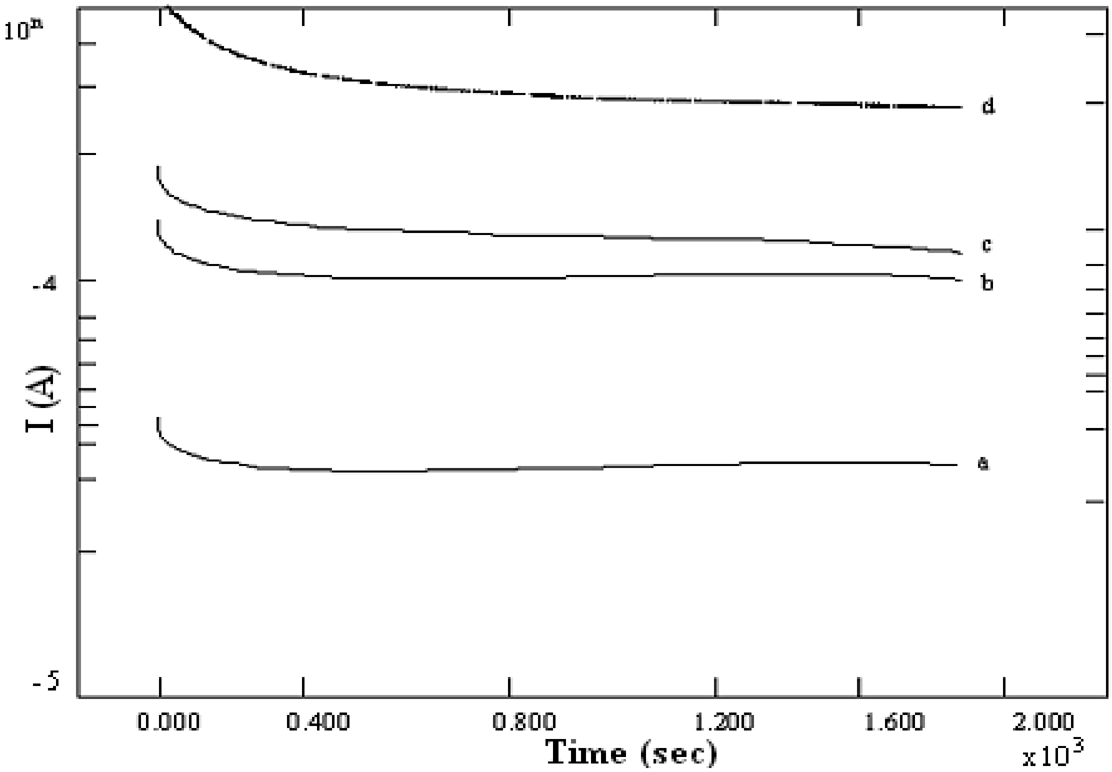

Fig. 5. Current – Time curve for calcium carbonate brine containing 300ppm of Ca^{2+} ions with the addition of MA - OT (60:40) polymer from constant potential electrolysis. (a) Blank (b) 5ppm (c) 10ppm (d) 20ppm.

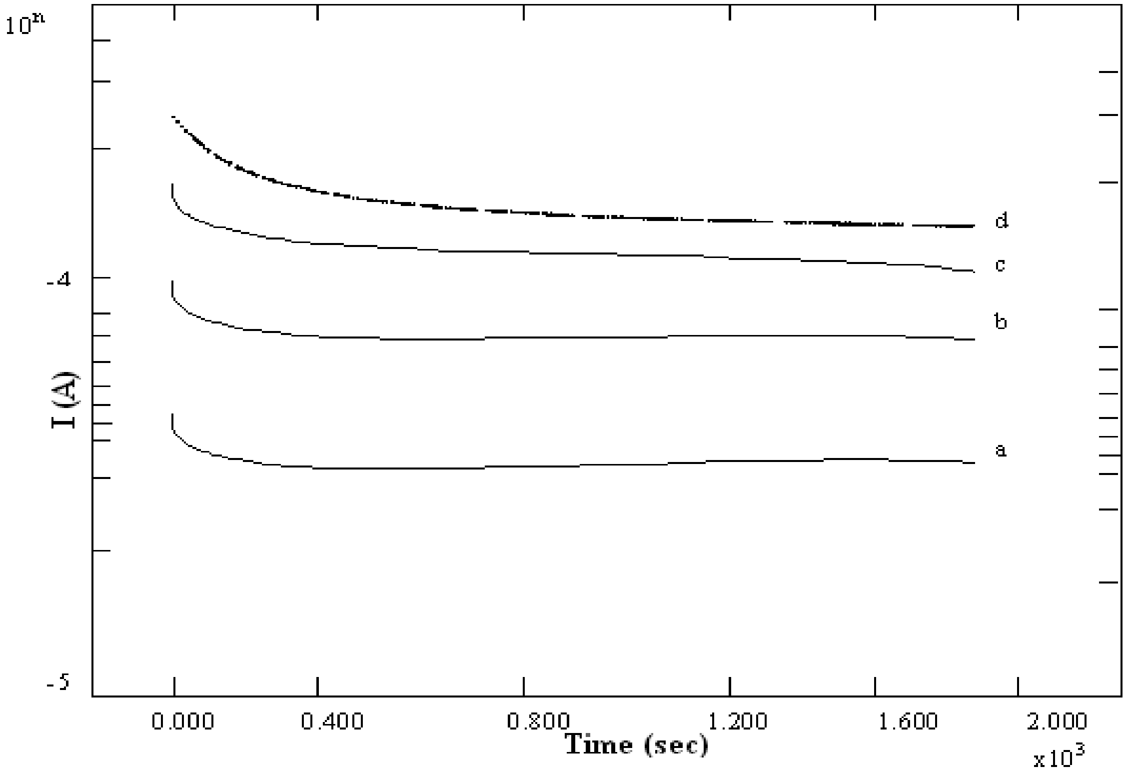

Fig. 6. Current – Time curve for calcium carbonate brine containing 300ppm of Ca^{2+}ions with the addition of MA - OT (40:60) polymer from constant potential electrolysis. (a) Blank (b) 5ppm (c) 10ppm (d) 20ppm.

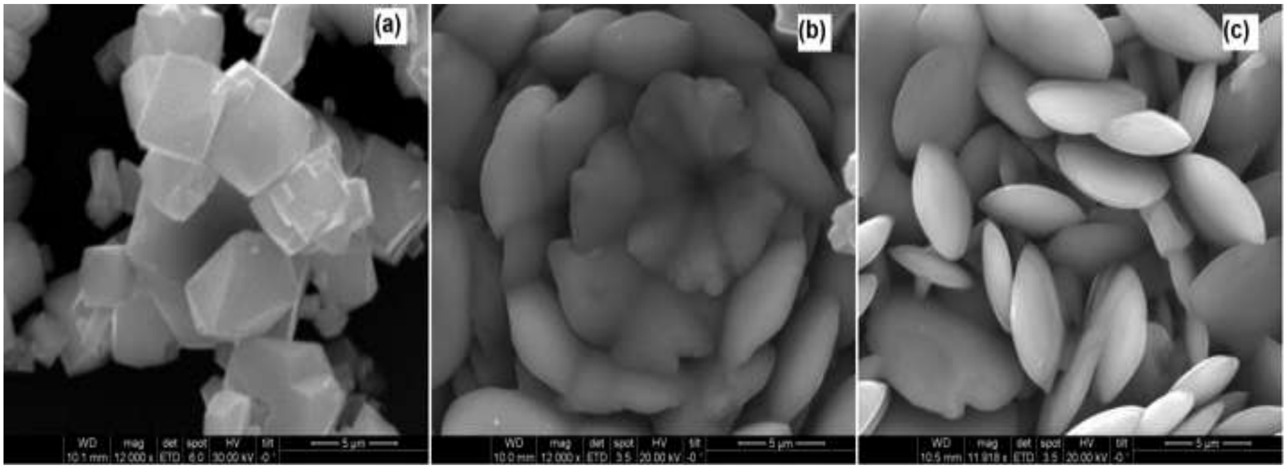

Fig. 7. SEM images of calcite precipitates in the absence and presence of inhibitor in jar test (a) blank (b) in presence of MA-OT (40:60) inhibitor (c) in presence of MA-OT (60:40) inhibitor.

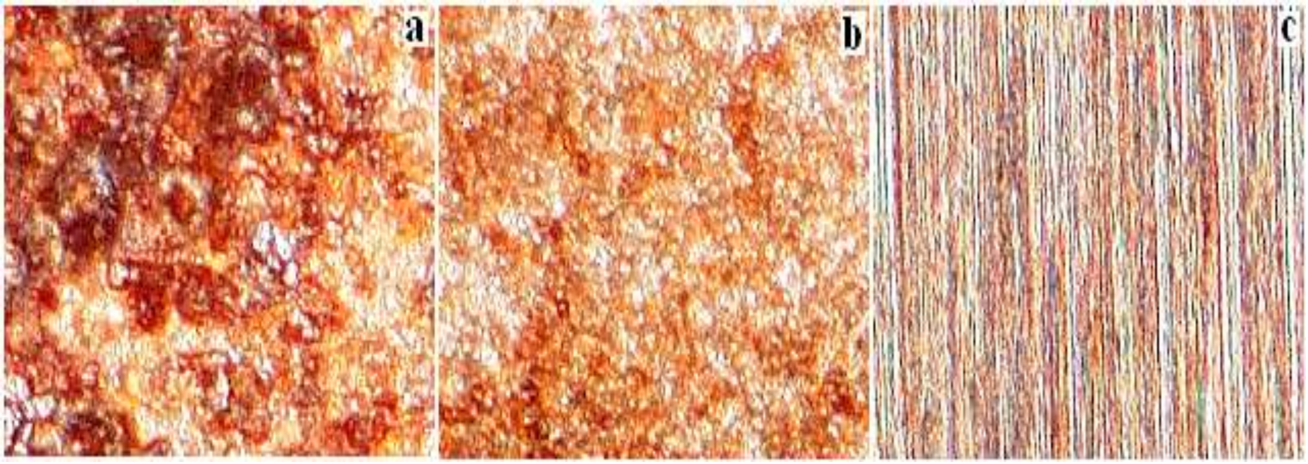

Fig. 8. Optical microscope images of corrosion on mild steel in the absence and presence of inhibitors (a) blank (b) with MA-OT (60:40) inhibitor (c) with MA-OT (40:60) inhibitor.

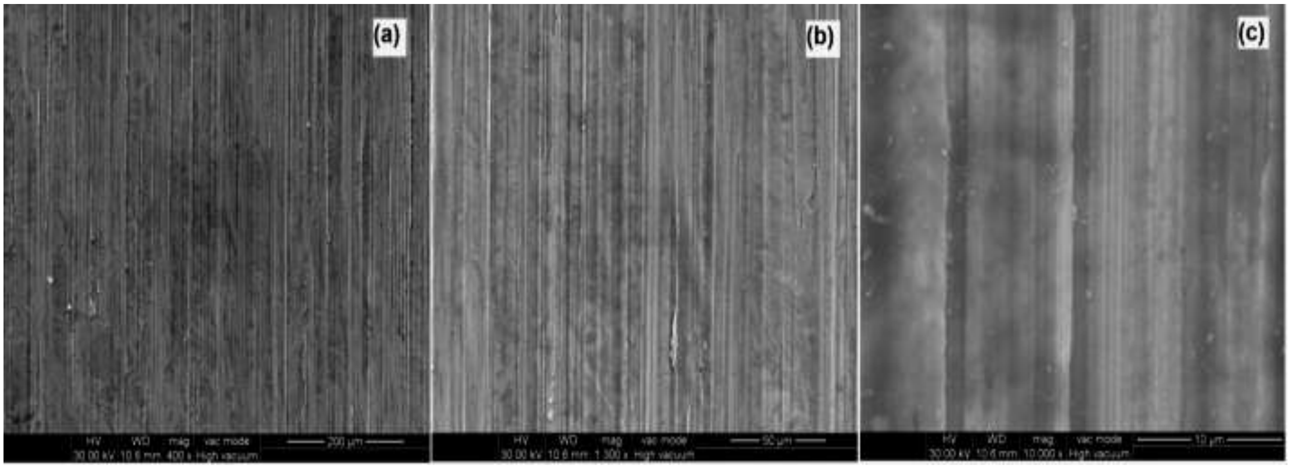

Fig. 9. SEM images of mild steel in the absence and presence of inhibitors (a) blank (b) with MA-OT (60:40) inhibitor (c) with MA-OT (40:60) inhibitor.

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