Scientia Iranica C (2012) 19 (6), 1665–1671

Sharif University of Technology

Scientia Iranica

Transactions C: Chemistry and Chemical Engineering

www.sciencedirect.com

Research note

Effect of acid additives on anticorrosive property of henna in regular mud acid

R. Abdollahi, S.R. Shadizadeh *

Department of Petroleum Engineering, Abadan Faculty of Petroleum Engineering, Petroleum University of Technology, Abadan, 6318714331, Iran

Received 3 August 2011; revised 31 May 2012; accepted 17 July 2012

KEYWORDS

Henna extract;
Corrosion inhibitor;
Regular mud acid;
Acid additives;
*N*80 *API* steel;
Electrochemical methods.

Abstract Many acid additives are used during acidizing treatment in order to prevent excessive corrosion, prevent sludge and emulsions, prevent iron precipitation, improve cleanup, improve coverage of the zone, and prevent precipitation of reaction products. Foremost among acid additives are corrosion inhibitors; therefore compatibility of other additives with corrosion inhibitor is very critical to the success of acidizing treatment. Any additive that alters the tendency of the corrosion inhibitor to adsorb on casing and tubing will also change its effectiveness. In present work, the inhibitive action of henna extract on corrosion of *N*80 *API* steel in regular mud acid (HCL/HF 12/3 wt%) at 28 °C was investigated through electrochemical technique. After determining the optimum concentration of henna extract, effect of acid additives on inhibitive action of henna extract on corrosion behavior of *N*80 steel in regular mud acid was investigated through polarization measurement and electrochemical impedance spectrometry methods. Inhibition efficiency of henna extract as a corrosion inhibitor for *N*80 *API* steel in regular mud acid at 28 °C is 85.98% (average of three methods). The results show that except iron control additive, all additives decrease the performance of henna extract as corrosion inhibitor.

1. Introduction

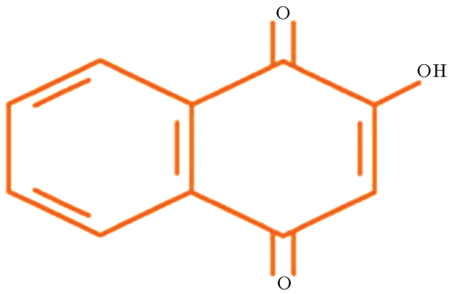
Matrix and fracture acidizing of sandstone and carbonate reservoirs are techniques for stimulating oil and gas reservoirs to produce at higher rates. Acids dissolve rock or permeability plug fines near the wellbore [1]. Hydrochloric acid (HCL) is the most commonly used acid in oil well stimulation. Hydrofluoric Acid (HF) is used in combination with HCI and has been referred to as "intensified acid" or "mud removal" acid. The most common mixture used in sandstone acidizing is regular mud acid (HCL/HF 12/3 wt%). HF is used primarily to remove clay-particle damage in sandstone formations, to improve permeability of clay-containing formations, and to increase solubility of dolomite formations [2]. Successful acidizing requires a working knowledge of formation damage, acid chemicals, and the mechanics of acid stimulation techniques. Proper fluid selection is critical to the success of a matrix treatment. The treatment may be a failure if the proper additives are not used. The treating fluid is designed to effectively remove or bypass the damage, whereas additives are used to prevent excessive corrosion, to prevent sludging and emulsions, to prevent iron precipitation, to improve cleanup, and to prevent the precipitation of reaction products [2]. A common problem in the use of multiple additives is that two or more additives are incompatible with one another. Although service companies have guidelines for additive use, it is not inconceivable that they may not be consulted properly. Consequently, those additives may be included which are not compatible. Corrosion inhibitors are the foremost among acid additives. A corrosion inhibitor is a chemical that slows the attack of acid corrosion on drill pipe, tubing or any other metal that the acid contacts during treatment. A great number of scientific studies have been dedicated to the subject of corrosion inhibitors for oil well casing and tubing in acidic media. Although many synthetic compounds show inhibitive action, most of them are toxic. There is increasing concern about the toxicity of corrosion inhibitors in petroleum industry. Therefore, finding natural occurring substances as corrosion inhibitor is the subject of great practical significance [3]. Any

* Corresponding author.
E-mail address: shadizadeh@put.ac.ir (S.R. Shadizadeh).

Peer review under responsibility of Sharif University of Technology.

Production and hosting by Elsevier

1026-3098
doi:10.1016/j.scient.2012.09.006



Scheme 1: Lawsone structure ($C_{10}H_6O_3$).

additive that alters the tendency of the corrosion inhibitor to adsorb will also change its effectiveness. For example, surfactants added to acid for various purposes may form micelles that solubilize the inhibitor, thereby decreasing the tendency for the inhibitor to adsorb on the metal surface [2]. A few studies have investigated corrosion inhibition of henna extract on some metals, such as aluminium, iron, zinc and nickel in acidic and alkaline solutions [4–7].

It has been reported that henna leaves contain soluble matter, Lawsone (2-Hydroxy-l, 4-naphthoquinone), resin, tannin, coumarins, gallic acid and sterols [7]. The main components of henna extract are hydroxy aromatic compounds, such as tannin and Lawsone. The inhibitive action of tannin attributes to the formation of a passivating layer of tannates on the metal surface [8]. The main constituent of Henna extract is Lawsone. The structure of Lawsone is shown in Scheme 1. It contains benzene unit, p-benzoquinone unit and phenolic group. Chemically, the molecule of Lawsone is 2-hydroxy-1, 4-naphthoquinone [9].

Lawsone molecule is a ligand that can chelate with various metal cations forming complex compounds. Therefore, the formation of insoluble complex compounds, by combination of the metal cations and the Lawsone molecules adsorbed on the metal surface, is a probable interpretation of the observed inhibition action of lawsone [7].

In the acidic medium, derealization of the lone pair of electrons on hydroxyl group takes place resulting in the rearrangement lawasone structure. Such a rearrangement, in the presence of metal cations, enhances the complex formation reaction.

In present work, the inhibitive action of henna extract on corrosion of *N*80 *API* steel in regular mud acid (HCL/HF 12/3 wt%) at 28 °C was investigated through electrochemical technique. After determining the optimum concentration of henna extract (1.6 g/l), the effect of acid additives on inhibitive action of henna extract on corrosion behavior of *N*80 steel in regular mud acid (HCL/HF 12/3 wt%) was investigated through polarization measurement and electrochemical impedance spectrometry methods. Additives were prepared from Iranian CymanBand Company (Table 1).

Table 1: Standard dosage and general property of additives used in this work (additives were prepared from Iranian CymanBand Company).

Surfactant	
Surf-27	Product name:
Clear liquid	Appearance:
1.057 g/cm^3	Specific gravity at 20 °F:
Mild	Odor:
250 °C	Flash point
200 °C at atmospheric pressure	Boiling point/boiling range:
100% at 20 °C	Solubility in water:
<0.01 hPa at 20 °C	Vapor pressure:
Non-ionic	Ionic nature:
2 gallons per 1000	Usual concentration
Multi function surfactant	
Multi-10	Product name:
Clear/yellow liquid	Appearance:
0.90–0.93 g/cm^3	Specific gravity at 16 °C:
46 °C	Flash point:
Cationic/nonionic	Ionic character:
0.1%–1% vol.	Usual concentration:
Suspended agent	
Suspend-28R	Product name:
Yellow liquid	Appearance:
0.89 g/cm^3	Specific gravity at 20 °F:
20 °C	Flash point:
29 °C	Pour point:
Cationic	Ionic character:
6–8	PH:
0.2%–1% vol.	Usual concentration:
Iron control agent	
Safety-IRONOUT-1L-M	Product name:
Yellow liquid	Appearance:
1.6 g/cm^3	Specific gravity at 20 °F:
153 °C	Change in physical property (melting point)
Hydroxy Propane Tricarboxylic acid	Description
Water and alcohol	Solubility:
2.1	PH:
25–200 pptg	Usual concentration:
Antisludge	
Nonsludge-20	Product name:
Brown liquid	Appearance:
0.99–1.0 g/cm^3	Specific gravity at 60 °F:
Anionic	Ionic nature:
13 °C	Flash point:
Minus 20 °C	Pour point:
13 °C	Flash point:
6–8	PH:
1%–2% vol.	Usual concentration:
Mutual solvent	
Mutual solvent-2	Product name:
Colorless liquid	Appearance:
0.95 g/cm^3	Specific gravity at 77 °F:
174 °F	Flash point:
41–44.5 °F	Pour point:
Water, acid and oil	Solubility:
5%–10% by volume	Usual concentration:

2. Experimental methods and procedures

2.1. Preparation of henna extract

Henna leaves were crushed and extracted in boiled water for 2 h. The extracted solution was then filtered and concentrated until the water from the extract evaporates. This solid extract was used to study the corrosion inhibition properties and to prepare the required concentrations of henna [7].

2.2. Specimen preparation

*N*80 steel specimens having nominal composition of 0.36% C, 0.27% Si, 1.57% Mn, 0.02% P and 0.14% V and Fe balance were used. Coupons were cut into 6 × 1.5 × 0.3 cm dimensions used for weight loss measurements, specimens with 1.5 × 1 × 3 cm dimensions, sealed by polyester resin, leaving a surface area of 1.5 cm^2, were used as working electrode for polarization and EIS measurements. Prior to carrying out the corrosion tests, the

metal specimens were mechanically ground successively with, 220, 400, 800, 1000, 1200 grade of emery paper, de-greased with acetone and rinsed by distilled water.

2.3. Solution preparation

Mud acid solution was prepared by mixture of HCL with ammonium bifluoride. One liter of regular mud acid (HCl/HF 12/3 wt%) was prepared by mixing of 959 ml HCL 15.4% with 46 g ammonium bifluoride. Standard dosage of each additive introduced separately to the regular mud acid that contained optimum quantity of henna extract. HF acid has corrosive effect on glassy apparatus and cannot be used in glassy experimental instruments. Therefore, all apparatus that contact with HF acid were comprised of plastic or Teflon materials.

2.4. Weight loss measurements

Experiments were performed at 28 °C with different concentration of henna extract (0.2–1.6 g/l). The immersion time for the weight loss is 8 h without any agitation in the solution during the test. Before recording the solution was de-aerated for 30 min. The inhibition efficiency (*IE* %) was calculated using the relation:

$$IE\% = \left(\frac{W_1 - W_2}{W_1}\right) \times 100, \tag{1}$$

where W_2 and W_1 are the weight losses of *N*80 *API* steel in the presence and absence of inhibitor, respectively. All the specimens were weighted on an analytical balance to an accuracy of ±0.01 mg.

2.5. Electrochemical tests

2.5.1. Polarization measurements

Corrosion normally occurs at a rate determined by equilibrium between opposing electrochemical reactions. The first is the anodic reaction, in which a metal is oxidized, releasing electrons into the metal. The other is the cathodic reaction, in which a solution species (often O_2 or H^+) is reduced, removing electrons from the metal. When these two reactions are in equilibrium, the flow of electrons from each reaction is balanced, and no net electron flow (electrical current) occurs [10].

Because corrosion occurs via electrochemical reactions, electrochemical techniques are ideal for the study of the corrosion processes. In electrochemical studies, a metal sample with a surface area of a few square centimeters is used to model the metal in a corroding system. The metal sample is immersed in a solution typical of the environment of the metal in the system being studied. Additional electrodes are immersed in the solution, and all the electrodes are connected to a device called a potentiostat. A potentiostat allows you to change the potential of the metal sample in a controlled manner and measure the current flows as a function of potential.

When the potential of a metal sample in solution is forced away from Open Circuit Potential (OCP), it is referred to as polarizing the sample. The response (current) of the metal sample is measured as it is polarized. The response is used to develop a model of the sample's corrosion behavior.

In the present work, electrochemical measurements were carried out in a conventional three- electrode glass cell, containing 300 ml of electrolyte at the temperature 28 °C. As previously mentioned, in media that HF acid exists, the use of glassy apparatus is not recommended. Therefore, Teflon material electrodes were used. The working electrode, which was embedded in polyester resin, had a geometric area of 1.5 cm^2. Platinum electrode was used as a counter electrode and a Saturated Calomel Electrode (SCE) as the reference electrode. All electrochemical experiments were carried out using an Autolab potentiostat PGSTAT 302 N (Eco Chemie, Utrecht, The Netherlands) driven by the General Purpose Electrochemical Systems data processing software (GPES, software version 4.9). Cathodic and anodic polarization curves were recorded at a rate of 1 mV/s in a range of 200 mV more than OCP and 200 mV less than OCP. Current density of each polarization curves is determined by intersection of cathodic Tafel slope and vertical line passing through E_{Corr} point. Before the recording, the solution was de-aerated for 30 min and the working electrode was maintained at its corrosion potential for 25 min, until a steady state was obtained. The inhibition efficiency *IE* % was calculated using the following relation:

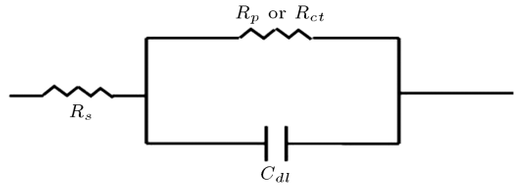


Figure 1: Equivalent Circuit (EC) for 3 simple corrosion systems under charge transfer control.

$$\%IE = \frac{I_0 - I}{I_0} \times 100, \tag{2}$$

where I and I_0 are the corrosion current densities of carbon steel in the presence and absence of inhibitor respectively.

2.5.2. Electrochemical impedance spectroscopy (EIS)

Simple corrosion systems which are entirely under charge transfer control and the cases of uniform corrosion on homogeneous surfaces can be described by the simple equivalent circuit (EC) in Figure 1. This EC allows the establishment of correlations between electrochemical system parameters and characteristic impedance elements [11]. In Figure 1, C_{dl} is the capacitance of the electrode surface and R_p is the polarization resistance which is inversely proportional to the corrosion current density i_{corr}

$$R_p = \frac{B}{i_{\text{corr}}}, \tag{3}$$

where B is a combination of the Tafel slopes b_a and b_c:

$$B = \frac{b_a b_c}{2.3(b_a + b_c)}. \tag{4}$$

All ohmic resistances under study in the system, such as the electrolyte resistance, cable resistances, etc., are contained in R_s, the solution resistance term.

The impedance modulus $Z(j\omega)$ for the EC in Figure 1 can be expressed as a function of frequency $f = \frac{\omega}{2\pi}$ as follows:

$$Z(j\omega) = R_s + \frac{R_p}{(1 + j\omega C_{\text{dl}} R_p)}. \tag{5}$$

The values of R_s and R_p can be determined from the high (Eq. (6)) and low (Eq. (7)) frequency limits of the measured impedance spectra, respectively.

Various approaches can be used to determine the experimental value of C_{dl} as described below.

Table 2: Corrosion rate and inhibition efficiency of *N*80 steel immersed in regular mud acid (HCL/HF 12/3 wt%) at 28 °C.

Concentration of henna (g/l)	W (mg/cm^2 h)	IE (%)
Temperature (K) = 301.15		
0.0	1.56	–
0.2	0.60	61.01
0.4	0.57	63.00
0.6	0.45	70.70
0.8	0.42	72.50
1.0	0.37	76.33
1.2	0.33	78.46
1.4	0.29	81.20
1.6	0.27	84.21

The different methods most commonly used for the display of experimental impedance data and the corresponding analysis routines which are part of the BASICS software package will now be described in general terms [11].

$$R_s = \lim_{f\to\infty} |Z|, \tag{6}$$

$$R_s + R_p = \lim_{f\to 0} |Z|, \tag{7}$$

$$C_{\mathrm{dl}} = \frac{1}{2\pi f_{\max} R_p}. \tag{8}$$

In present work, electrochemical measurements were carried out in a conventional three electrode glass cell with the same electrodes used in polarization measurements at the temperature of 28 °C. Electrochemical impedance spectroscopy measurement was performed with Autolab potentiostat PGSTAT 302 N (Eco Chemie, Utrecht, The Netherlands) driven by Frequency Response Analyzer data processing software (FRA software version 4.9). Frequency ranging was selected between 100 MHz and 10 kHz and peak-to-peak a.c. amplitude of 10 mV was used for calculation of polarization resistance values (R_p) and the double layer capacitance (C_{dl}). Data obtained by EIS measurement is expressed graphically in a Nyquist plot. Before recording the solution was de-aerated for 30 min. The inhibition efficiency *IE %* was calculated using the following relation:

$$IE\% = \left(\frac{R_2 - R_1}{R_2}\right) \times 100, \tag{9}$$

where $R1$ and $R2$ are the polarization resistance of *N*80 steel in the absence and presence of inhibitor, respectively.

3. Results and discussion

3.1. Weight loss measurements

The corrosion rate and inhibition efficiency for *N*80 steel in regular mud acid (HCL/HF 12/3 wt%) at 28 °C in various concentrations of henna extract is determined after 8 h of immersion. Values of corrosion rate and inhibition efficiencies are given in Table 2. It is clear from Table 2 that corrosion rate decreases more and more with the increase of henna extract. Inhibition efficiency increases with the increase of henna concentration to attain 84.21% at 1.6 g/l of henna extract at 28 °C.

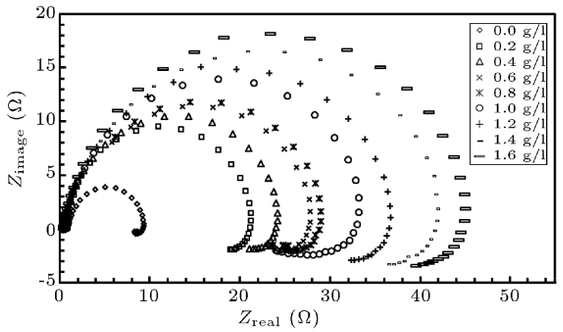


Figure 2: Nyquist plots for *N*80 in regular mud acid (HCL/HF 12/3 wt%) containing different concentrations of henna extract at 28 ± 1 °C.

Table 3: Impedance parameters of *N*80 steel in regular mud acid (HCL/HF 12/3 wt%) containing different concentrations of henna extract at 28 °C.

Henna concentration (g/l)	R_P (Ω)	$f_{\max}$ (Hz)	C_{dl} (μF/cm^2)	IE (%)
Temperature = 301.15 K				
0.0	8.500	51.8	240.66	–
0.2	20.93	21.2	239.04	59.40
0.4	24.09	37.3	120.82	64.72
0.6	27.71	37.3	102.69	69.33
0.8	28.77	37.3	99.05	70.45
1.0	33.57	37.3	84.75	74.68
1.2	36.86	37.3	72.20	76.94
1.4	41.55	37.3	68.48	79.54
1.6	45.00	37.3	63.245	81.11

3.2. EIS measurements

The corrosion behavior of *N*80 steel in regular mud acid (HCL/HF 12/3 wt%) solution at 28 °C in various concentrations of henna extract was investigated by EIS experiments. The data obtained by EIS measurements is expressed graphically in a Nyquist plot (Figure 2). By analyzing the Nyquist representation of EIS experiment, it shows that the curves approximated by single capacitive semi-circles, showing that corrosion process was mainly charge transfer controlled [12]. The impedance parameters (polarization resistance (R_p), double layer capacitance (C_{dl}), and inhabitation efficiency (*IE %*)) are given in Table 3. The results show that in the presence of henna extract, polarization resistance (R_p) increase from 8.500 to 45.00 (Ω) and double layer capacitance C_{dl} decreases from 240.666 to 63.245 μF/cm^2 at 28 °C. The increase in the polarization resistance leads to an increase in inhabitation efficiency. The shape is maintained throughout the whole concentration, indicating that almost no change in the corrosion mechanism occurred due to the inhibitor addition.

The effect of each acid additive on the performance of henna extract as a corrosion inhibitor for *N*80 *API* steel immersed in regular mud acid was investigated by EIS experiment. The obtained data by EIS measurements is expressed graphically in a Nyquist plot (Figure 3). The impedance parameters of each solution (polarization resistance (R_p), double layer capacitance (C_{dl}), and inhibition efficiency (*IE %*)) are given in Table 4. The results show that except iron control additive, all additives used in the current study decrease the performance of henna extract as a corrosion inhibitor. Antisludge, surfactant, mutual solvent, suspended agent, and multifunction agent have greater effect on decreasing the performance of henna extract as a corrosion inhibitor, respectively. A blend of all additives causes the polarization resistance (R_p) to decrease from 45 to 27, double

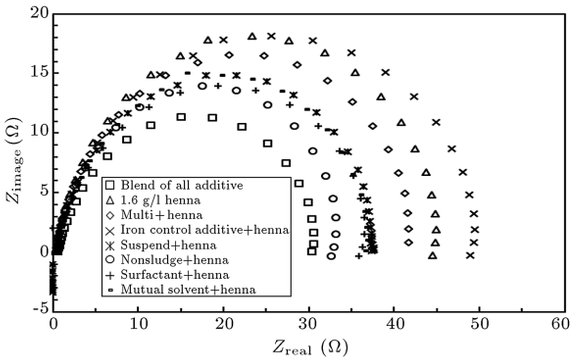


Figure 3: Nyquist plots for *N*80 in regular mud acid (HCL/HF 12/3 wt%) containing optimum concentrations of henna extract and blend of optimum concentration of henna and standard dosage of each additive at 28 ± 1 °C.

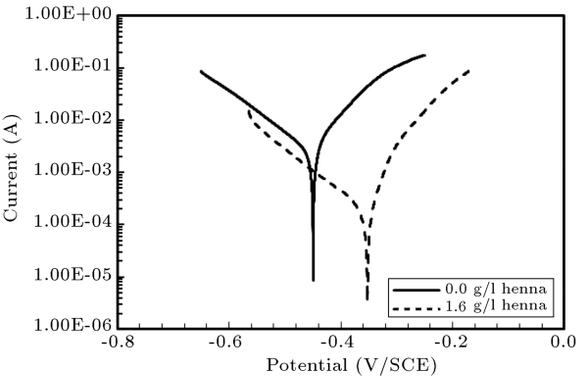


Figure 4: Polarization curves for *N*80 steel in regular mud acid (HCL/HF 12/3 wt%) in the absence and presence of optimum concentration of henna extract (1.6 g/l) at 28 °C.

Table 4: Effect of acidizing additive on impedance parameters of *N*80 steel in regular mud acid (HCL/HF 12/3 wt%) containing optimum concentration of henna extract as a corrosion inhibitor at 28 °C.

Medium	RP (Ω)	f_{max} (Hz)	C_{dl} (μF/cm^2)	IE (%)
Temperature = 28 °C				
1.6 g/l henna extract	45.00	37.3	63.245	81.11
1.6 g/l henna extract + iron control agent	49.51	37.3	57.428	82.83
1.6 g/l henna extract + multifunction surfactant	41.94	37.3	67.859	79.73
1.6 g/l henna extract + suspended agent	37.22	43.7	65.266	77.16
1.6 g/l henna extract + mutual solvent	36.75	37.3	77.423	76.87
1.6 g/l henna extract + surfactant	36.53	37.3	77.909	76.73
1.6 g/l henna extract + antisludge	33.21	37.3	113.674	74.40
Blend of all additives	27.00	37.3	92.900	72.25

Table 6: Effect of acidizing additive on kinetic parameters of *N*80 steel in regular mud acid (HCL/HF 12/3 wt%) containing optimum concentration of henna extract as a corrosion inhibitor at 28 °C.

Medium	$-\beta$ (mV/dec)	E_{corr} (mv/SCE)	I_{corr} (mA/cm^2)	IE (%)
Temperature = 28 °C				
1.6 g/l henna extract	120	−333	0.113	92.62
1.6 g/l henna extract + iron control agent	102	−372	0.086	94.34
1.6 g/l henna extract + multifunction surfactant	101	−373	0.134	91.30
1.6 g/l henna extract + suspended agent	139	−389	0.200	86.08
1.6 g/l henna extract + mutual solvent	99	−372	0.193	87.39
1.6 g/l henna extract + surfactant	118	−377	0.240	84.34
1.6 g/l henna extract + antisludge	125	−391	0.267	82.60
Blend of all additives	121	−393	0.334	78.26

layer capacitance C_{dl} to increase from 63.245 to 92.900 μF/cm^2 and *IE* % to decrease from 82.83% to 72.75% at 28 °C. These additives alter the tendency of henna extract to adsorb on *N*80 *API* steel surface and decrease the inhibitive performance of henna extract.

3.3. Polarization measurements

The potentiodynamic polarization curves of *N*80 *API* steel immersed in regular mud acid (HCL/HF 12/3 wt%) solution in the absence and presences of optimum concentration of henna extract at 28 °C are shown in Figure 4. The corrosion parameters including corrosion current density (I_{corr}), corrosion potential (E_{corr}), cathodic Tafel slope (β_c), and inhibition efficiency (*IE* %) are given in Table 5. In the presence of this inhibitor, the corrosion of the current density decreases from 1.533 mA/cm^2 to 0.113 mA/cm^2. This suggests the inhibitive nature of this inhibitor system. Cathodic branches marks shift in the presence of henna extract and the value of corrosion potential is increased. Therefore, the henna extract acts as inhibitor with cathodic effectiveness. The effect of each acid additive on inhibitation performance of henna extract is investigated by polarization measurements (Figure 5). The corrosion parameters of each solution including corrosion current density (I_{corr}), corrosion potential (E_{corr}), cathodic Tafel slope (β_c), and inhibition efficiency (*IE* %) are given in Table 6. The results show that except iron control additive, all used additives decrease the performance of henna extract as a corrosion inhibitor. Antisludge, surfactant, mutual solvent, suspended agent, and multifunction agent have greater effect on decreasing the performance of henna extract as a corrosion inhibitor, respectively. A blend of all additives caused *IE* % to decrease from 92.62% to 67% at 28 °C.

Inhibition efficiency values obtained from polarization measurements are in good agreements with electrochemical impedance spectrometry method and weight loss measurements. This demonstrates the fact that the corrosion rate depends on the chemical nature of the electrolyte and the temperature of the medium, rather than the applied technique.

Table 5: Kinetic parameters of *N*80 steel in regular mud acid (HCL/HF 12/3 wt%) containing optimum concentrations of henna extract and blank acid at 28 °C.

Temperature (K)	Henna concentration (g/l)	$-\beta_C$ (mV/dec)	E_{Corr} (mV/SCE)	I_{Corr}(mA/cm^2)	IE (%)
301.15	0	120	−450	1.533	–
301.15	1.6	117	−333	0.113	92.62

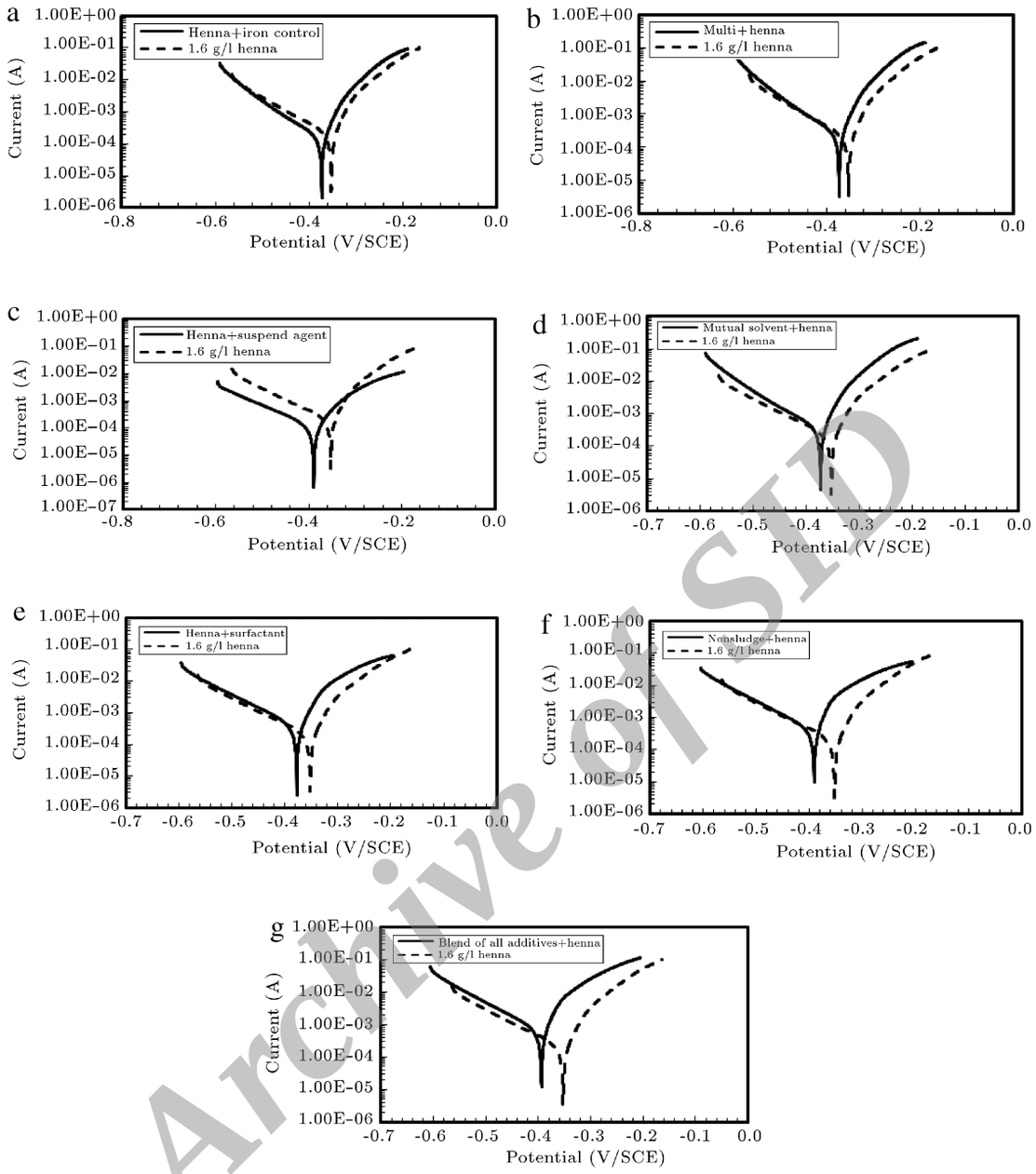


Figure 5: Polarization curves for *N*80 steel immersed in inhibited regular mud acid (dash line) and in regular mud acid containing 1.6 g/l henna and standard dosage of acidizing additive at 28 °C. (a) Iron control agent; (b) multifunctional surfactant; (c) suspended agent; (d) mutual solvent; (e) surfactant; (f) nonsludge; and (g) blend of all additives agent.

3.4. Comparison of henna extract with other inhibitors

Previous studies on inhibition property of henna extract as a corrosion inhibitor in acidic media is not sufficient to use henna extract in acid stimulation. Because in these studies the acid concentration is less than the actual value of acid concentration used for acid stimulation (like corrosion inhibition of mild steel in 1 M HCl solution by henna extract listed in Table 7). Also, up to now there is no study on inhibition property of acidizing inhibitor for *N*80 steel in regular mud acid; therefore, inhibition property of henna is compared with some inhibitor use for inhibition of *N*80 *API* steel in HCL 15% which approximately have the same corrosive effect like regular mud acid on casing and tubing [13,14]. Table 7 represents the inhibition efficiency of henna and 5 organic inhibitors used in acidizing treatment.

Inhibition efficiency of henna extract, MEA, DEA and TEA at 28 °C is 85.98%, 82%, 80% and 78%, respectively; therefore, inhibition efficiency of henna extract at 28 °C is higher than MEA, DEA and TEA. As shown in Table 7, the inhibition efficiency of henna extract increases with the increase of temperature; therefore *IE* % of henna extract at 105 °C is higher than 92.59% (92.59% is *IE* % of henna at 75 °C). As shown in Table 7, the *IE* % of DDABA and DBA at 105 °C are 73.8% and 99.7%, respectively; therefore, the inhibition efficiency of henna extract at 28 °C is higher than DDABA.

Also, the results show that, the optimum concentration of henna extract is less than all of inhibitors listed in Table 7.

Table 7: Inhibition efficiency of MEA, DEA, TEA and henna for *N*80 API steel.

Type of inhibitor	Medium (wt%)	Specimen	Temperature (°C)	Inhibitor concentration (ppm)	IE (%)	Reference no.
Monoethanolamine (MEA)	HCL 15	*N*80	28	2000	82	[13]
Diethanolamines (DEA)	HCL 15	*N*80	28	2000	80	[13]
Triethanolamines (TEA)	HCL 15	*N*80	28	2000	78	[13]
Dibenzylidene acetone (DBA)	HCL 15	*N*80	105	5000	99.7	[14]
Di-N-dimethylaminobenzylidene acetone (DDABA)	HCL 15	*N*80	105	5000	73.8	[14]
Henna	HCL/HF 12/3	*N*80	28	1600	85.98	
Henna	HCL 3	Mild steel	28	1200	92.06	[7]

In order to identify the efficiency of henna extract as a corrosion inhibitor, henna is compared with some inhibitors used in acidizing treatment. So far, no study has been performed on inhibition property of acidizing inhibitor for *N*80 steel in regular mud acid.

4. Conclusions

1. Inhibition efficiency of henna extract as a corrosion inhibitor for *N*80 *API* steel in regular mud acid at 28 °C is 85.98% (average of three methods). Thus, henna extract has admissible inhibition efficiency for inhibition of *N*80 *API* steel in regular mud acid at 28 °C.
2. The results show that except iron control additive, all additives used in this work decrease the performance of henna extract as a corrosion inhibitor.
3. Antisludge, surfactant, mutual solvent, suspended agent, and multifunction agent have greater effect on decreasing the performance of henna extract as a corrosion inhibitor, respectively.

Acknowledgments

The authors thank Research and Development Department of National Iranian South Oil Company (NISOC) for the support provided over the course of this work.

References

[1] Coulter, G.R. and Jennings, A.R. "A contemporary approach to matrix acidizing", *Journal of SPE Production and Facilities*, 14(2), pp. 144–149 (1999).
[2] Economides, M.J. and Nolte, K.G., *Reservoir Stimulation*, 3rd Edn., Schlumberger, John Wiley & Sons Ltd. (2000).
[3] Williams, B.B., Gidley, J.L. and Schechter, R.S., *Acidizing fundamentals*, In *SPE Monograph*, p. 124 (1979).
[4] El-Etre, A.Y., Abdallah, M. and El-Tantavvy, Z.E. "Corrosion inhibition of some metals using Lawsonia extract", *Corrosion Science*, 47, pp. 385–395 (2005).
[5] Chetouani, A. and Hammouti, B. "Corrosion inhibition of iron in hydrochloric acid solutions by naturally henna", *Bulletin of Electrochemistry*, 19, pp. 23–25 (2003).
[6] Al-Sehaibani, H. "Evaluation of extracts of henna leaves as environmentally friendly corrosion inhibitors for metals", *Materialwissenschaft und Werkstofftechnik*, 31, pp. 1060–1063 (2000).
[7] Ostovari, O., Hoseinieh, S.M., Peikari, M., Shadizadeh, S.R. and Hashemi, S.J. "Corrosion inhibition of mild steel in 1 m HCL solution by henna extract: a comparative study of the inhibition by henna and its constituents (Lawsone, Gallic acid, α-d-glucose and tannic acid)", *Corrosion Science*, 51, pp. 1935–1949 (2009).
[8] Boot, G.H. and Mercer, S.J. "The effect of mimosa tannin on the corrosion of mild steel in the presence of sulphate-reducing bacteria", *Corrosion Science*, 4, pp. 425–433 (1964).
[9] Rajendran, S., Agasta, M., Bamadevi, R., Shyamaladev, B., Rajam, K. and Jeyasundari, J. "Corrosion inhibition by an aqueous extract of henna leaves (Lawsonia Inermis L)", *Zaštita Materijala*, 50, pp. 77–84 (2009).
[10] Fontana, M.G., *Corrosion Engineering*, 3rd Edn., Publisher McGraw-Hill Book Company (1986).
[11] Zaki, A., *Principals of Corrosion Engineering and Corrosion Control*, 1st Edn., Linacre House, Jordan Hill, Oxford OX2 8DP, UK (2006).
[12] Rosliza, R., Wan Nik, W.B. and Senin, H.B. "The effect of inhibitor on the corrosion of aluminum alloys in acidic solutions", *Materials Chemistry and Physics*, 107, pp. 281–288 (2008).
[13] Jayaperumal, D., Muralidharan, S., Venkatachari, G. and Rengaswamy, N.S. "Inhibition effect of ethanolamines on oil well tubular material in hydrochloric acid", *Anti-corrosion Methods and Materials Journal*, 47, pp. 349–353 (2000).
[14] Suroor Athar, S.M., Ali, H. and Ouraishi, M.A. "Study of some new organic inhibitors on corrosion of N-80 and mild steel in hydrochloric acid", *Anti-corrosion Methods and Materials Journal*, 48, pp. 251–254 (2001).

Reza Abdollahi has B.S. and M.S. in Petroleum Exploration Engineering from Petroleum University of Technology, Iran. His M.S. thesis is entitled "Experimental Investigation of Use of Henna Extract as a Corrosion Inhibitor for Acid Stimulation of Oil Wells: Prevention of Asphaltene Precipitation". His research areas are Natural Oil Production, and Laboratory Fluid Flow Through Porous Media.

Seyed R. Shadizadeh has Postdoctoral and Ph.D., M.Sc. and B.Sc. degrees in Petroleum Engineering from University of Oklahoma, USA. He is Vice Dean of Abadan Petroleum Engineering Collage of PUT. He has experience and proficiency in Petroleum Engineering along with 25 years of teaching in Universities. He has considerable experience of simulating reservoirs, drilling, oil recovery in USA and Iran, which has led to several international presentations in USA, Canada and Iran. His research areas are Fluid Flow Characteristics of Petroleum Reservoir, Enhances Oil Recovery, Drilling Technologies, Practical Drilling Optimization, Simulation of Hazardous Waste Deep Well Injection, Hydraulic Fracturing Well Design, Well Testing, and Reservoir Simulation.