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# Studies on the adsorption and inhibiting properties of Salix Babylonica Extract on corrosion of carbon steel in hydrochloric acid solutions

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#### 1. Introduction

# Abstract

The influence of *Salix babylonica extract* (SBE) on carbon steel (CS) corrosion in 1 molar HCl at 25°C has been investigated. Mass loss (ML) method, Tafel polarization (TP), AC impedance (EIS) and electrochemical frequency modulation (EFM) tests have been used to derive the corrosion parameters. The data obtained from both tests (EIS and EFM) are comparable with those obtained from Tafel extrapolation tests, approving confirmation calculation of corrosion rates of the final. The inhibiting action of SBE was discussed in terms of blocking the CS surface by molecules adsorbed on the active sites. The adsorption was found to obey Temkin isotherm. The morphology of protected and unprotected CS has been examined by different techniques like: Fourier transform infrared spectroscopy (FTIR), scanning electron microscope (SEM), energy dispersive X-ray (EDX) and atomic force microscope (AFM)

C-steel comprehensively utilized under various circumstances in petroleum productions [1]. Aqueous solutions containing acids are most destructive medium. Acidic solutions broadly utilize in manufacturing of oil well acidizing, pickling, acid washing of boilers and descaling [2–5]. Commonly, hydrochloric and sulfuric acids are engaging in such target [6]. The focal problem relating to applications of CS is its comparatively low corrosion resistance in acidic medium. Numerous tests utilize to control the CS corrosion. The most one methods are utilized organic inhibitor [7, 8]. In effect, inhibitors are heterocyclic composite that has bonds, P, S, O and N [9, 10]. However, most of the composite that establishes these inhibitors are toxic to environments and human. The poisonousness of these inorganic and organic inhibitors has gotten way to explore, utilize of non-toxic, natural products, composite [11-14] that are eco-friendly. The utilizing of extracts of some plants to control the CS corrosion in acid solution has been reported in the literature [15–32].

# 2. Experimental details

2.1. Synthesis

1.0 M HCl was used in the research laboratory by diluting the suitable volume of analytical grade, 37% HCl with bi-distilled water.

Table1: Chemical composition (weight %) of CS

| Element    | С     | Mn    | Fe   | Si    | Р     |
|------------|-------|-------|------|-------|-------|
| Weight (%) | 0.200 | 0.350 | Rest | 0.003 | 0.024 |

# 2.2. Preparation of SBE extract

The present study was carried out by utilizing the plant species SBE. The utilized parts were the leaves of Salix tree. The testers were picked from the plant and milled into powder to obtain 500 g of powdered materials; a recognized magnitude of the materials was soxholated utilized bi-distilled water. Lastly, the SBE was dried, weighed and kept at 4°C and saved for utilizing when needed.

# 2.3. Mass loss (ML) tests

Quadrilateral coins of CS with size  $(2.1 \text{ cm x } 2.0 \text{ cm x } 0.2 \text{ cm}) \times 2$  faces were abraded with dissimilar grades of emery papers, cleaned with bi-distilled water and dried by filter papers. After weighting exactly, the coins were immersed in 100 ml of acid with and withoutvarious doses of SBE extract at 25°C. After various dipping times, the CS coins were removed out and weighed again. The ML data have utilized to measure the corrosion rate (k<sub>corr</sub>) by eq. (1):

 $k_{corr} = (ML \text{ in gram } x \ 8.75 \ x \ 104) / DAT$ (1) Where the D = density of CS in g cm<sup>-3</sup>, A = area which exposed in cm<sup>2</sup>; T = time exposure in hr. The (%IE) and ( $\theta$ ) were measured from eq. (2): % IE =  $\theta \ x \ 100 = [(CR^* - CR) / CR^*] \ x \ 100$ (2) Where CR<sup>\*</sup> and CR are the corrosion rates of CS without and with various SBE, correspondingly.

#### 2.4. Electrochemical tests

The experiments were carried out potentiodynamically in a thermostated three electrode cell. Pt foil had utilized as counter electrode (1 cm<sup>2</sup>), a saturated calomel electrode (SCE) and the working electrode was in the form of a rectangular cut from CS under test. This electrode was dipped in 100 ml of a test solution for half hour to reach a steady state ( $E_{oc}$ ). The TP diagrams were obtained by exchanging the electrode potential from -1.0 to 0.0 V versus SCE. All tests were done in freshly prepared solution at temperature constant (25 ±1°C) utilizing a thermostat. IE% and the ( $\theta$ ) were gotten from eq.(3):

$$\% IE = \theta x \ 100 = \left[ (i_{corr} - i_{corr(inh)}) / i_{corr} \right] x \ 100 \tag{3}$$

Where  $i_{corr}$  and  $i_{corr(inh)}$  are the corrosion current data without and with extract, correspondingly, gotten by extrapolation of Tafel lines.

EIS spectra were obtained at ( $E_{OCP}$ ) after dipping the electrode for half hour in the investigated solution. The (% IE) and the ( $\theta$ ) of the utilized SBE extract obtained from the EIS tests were measured by applying the next relation:

% 
$$IE = \theta x \ 100 = [1 - (R_{ct}^{\circ}/R_{ct})] x \ 100$$

Where  $R^{o}_{ct}$  and  $R_{ct}$  are the charge transfer resistances in the attendance and absence of SBE extract, correspondingly.

EFM tests were achieved with relating potential perturbation signal with amplitude 10 mV with two sine waves of 2 and 5 Hz. [33]. The larger peaks were utilized to measure the corrosion current ( $i_{corr}$ ), the Tafel slopes ( $\beta_c$  and  $\beta_a$ ) and the causality factors CF-2 and CF-3 [34].

All electrochemical tests were done utilizing Gamry apparatus PCI300/4 Potentiostat/Galvanostat/Zra analyzer, DC105 software for TP, EIS300 software for EIS, EFM140 for EFM calculation and Echem Analyst 5.5 for outcome plotting, graphing, data fitting and computing.

#### 2.5. Surface analysis

The CS surface was prepared by keeping the coins for 1 day dipping in acidic with and without the optimum dose of SBE, after abrading by various emery papers up to 1200 grit size. Then, afterward this dipping time, the coins were cleaned gently with bi-distilled water, dried carefully. The corroded CS surfaces were analyzed utilizing an X-ray diffractometer Philips (PW-1390) with Cu-tube (Cu Ka1,  $l = 1.54051 \text{ A}^\circ$ ), a scanning electron microscope (SEM, JOEL, JSM-T20, Japan).

(4)

### 3. Result and Discussion

#### 3.1. Mass loss (ML) tests

The ML of CS coins was listed after various time intervals of immersion (30,60,90,120,150,180 min) at various temperatures (25 to 45°C); only the ML diagrams at 25°C are displayed here (Figure. 1). The %IE data at dissimilar temperatures are getting in Table 2. The obtained data show that the presence of SBE inhibited the corrosion of CS in acidic medium. The %IE was obtained at different concentrations of SBE extract and is recorded in Table 2. The adsorption of the extract molecules decreases the dissolution of the CS by blocking the corrosion center and hence lowering the ML and hence increase in the %IE as the dose of the SBE rises.



Figure 1: ML-time diagrams for the dissolution of CS in 1M HCl without and with various doses of SBE at 25°C

| [inh], ppm | 25    | 5°C  | 30    | 0°C  | 35    | °C   | 40    | 0°C  | 45    | °C   |
|------------|-------|------|-------|------|-------|------|-------|------|-------|------|
| Blank      | θ     | %IE  |
| 50         | 0.537 | 53.7 | 0.592 | 59.2 | 0.624 | 62.4 | 0.661 | 66.1 | 0.703 | 70.3 |
| 100        | 0.624 | 62.4 | 0.641 | 64.1 | 0.675 | 67.5 | 0.691 | 69.1 | 0.730 | 73.0 |
| 150        | 0.681 | 68.1 | 0.682 | 68.2 | 0.710 | 71.0 | 0.753 | 75.3 | 0.762 | 76.2 |
| 200        | 0.694 | 69.4 | 0.733 | 73.3 | 0.742 | 74.2 | 0.780 | 78.0 | 0.787 | 78.7 |
| 250        | 0.719 | 71.9 | 0.749 | 74.9 | 0.768 | 76.8 | 0.800 | 80.0 | 0.822 | 82.2 |
| 300        | 0.757 | 75.7 | 0.776 | 77.6 | 0.797 | 79.7 | 0.815 | 81.5 | 0.840 | 84.0 |

**Table 2:** Effect of temperature on  $(\theta)$  and (%IE) of SBE at various doses

# 3.2. Adsorption isotherms

The obtained data of  $(\theta)$  for dissimilar doses of SBE were estimated from ML. From the data of  $(\theta)$ , it can be seen that these data improved by raising the dose of SBE. Utilizing these data of  $(\theta)$ , one can utilize dissimilar isotherms that agreed with the obtained values. In this research, Temkin isotherm was established to be most appropriate for the finding experimental data. This isotherm is selected by eq. (5).

$$2a\Theta = \ln (K_{ads} C)$$

Where a = heterogeneous factor on CS surface. ( $K_{ads}$ ) is the adsorption equilibrium constant, which can be utilized to measure ( $\Delta G^{o}_{ads}$ ) as next eq.(6):

 $\Delta G^{o}_{ads} = - RT \ln (55.5 K_{ads})$ 

(6)

(5)

Where 55.5 is the water dose in the solution in  $M^{-1}$ . The parameters obtained from adsorption process were listed in Table (3). The -ve sign of  $\Delta G^{\circ}_{ads}$  and rise as the % IE rise, which designate that this SBE are strongly adsorbed on the CS surface and show the spontaneity of the process. Commonly, data of  $\Delta G^{\circ}_{ads}$  up to -20 kJ mol<sup>-1</sup> are reliable with the electrostatic interaction among the charged molecules and metal (adsorption physical) while those more negative than - 40 kJ mol<sup>-1</sup> include sharing or transfer of electrons from the SBE molecules to the CS surface to form a coordinate kind bond (chemisorption)[35]. The data of  $\Delta G^{\circ}_{ads}$  obtained were around to (29.3-39.6) kJ mol<sup>-1</sup>, lead to that the mechanism of adsorption of the SBE on CS includes both physical and chemical adsorption [36, 37]



Figure 2: 0 vs. log C of SBE for corrosion of CS in acidic solution from ML tests at 25°C

| Table 3: | parameters | obtained | from | adsorptio | 1 process | of SBE | on CS | in I M | HCl at | various | temperatures |
|----------|------------|----------|------|-----------|-----------|--------|-------|--------|--------|---------|--------------|
|----------|------------|----------|------|-----------|-----------|--------|-------|--------|--------|---------|--------------|

| Temp. | $K_{ads} \times 10^{-2}$ | $-\Delta G^{\circ}_{ads}$ | $-\Delta H^{\circ}_{ads}$ | $-\Delta S^{\circ}_{ads}$ |
|-------|--------------------------|---------------------------|---------------------------|---------------------------|
| (K)   | M <sup>-1</sup>          | $(kJ mol^{-1})$           | (kJ mol)                  | $(J mol^{-1} K^{-1})$     |
| 298   | 20.1                     | 29.3                      |                           | 97.7                      |
| 303   | 51.7                     | 32.7                      |                           | 107.4                     |
| 308   | 135.2                    | 36.3                      | 158.8                     | 117.5                     |
| 313   | 221.6                    | 38.8                      |                           | 123.5                     |
| 318   | 1579.1                   | 39.6                      |                           | 124.1                     |

# 3.3. Temperature effect

ML of CS in 1.0 M HCl was carried out at various temperatures (25–45°C) without and with various doses of SBE. The influence of increasing temperature on the ( $k_{corr}$ ) and % IE was obtained from ML tests. The obtained data showed that with temperature rise,  $k_{corr}$  is lowered, while % IE rises. Figure.3 indicates the Arrhenius diagrams of natural logarithm of  $k_{corr}$  against 1/T, for CS in acidic solution, without and with various doses of SBE. The obtained data of slopes of these straight lines permit the measure of the activation energy,  $E_a^*$ , using eq. (7):

$$k_{corr} = A \exp\left(-E_a^*/RT\right)$$

(7)

Where A is the pre-exponential factor. The  $E_a^*$  data obtained are listed in table (4), the  $E_a^*$  is decreased in the presence of SBE than in its absence. This was due to the lower rate of adsorption of SBE when approached to equilibrium during the experiments at maximum temperatures according to Hoar and Holiday [38]. However, Riggs and Hurd [39] reported that the lower in the  $E_a^*$  of corrosion due to increase in extract concentration arises from a shift of the net corrosion reaction from the uncovered part of the CS surface to the protected one.  $\Delta G^* = RT [ln (kT/h) - ln k_{corr}$  (8) The  $(\Delta H^*)$  and  $(\Delta S^*)$  were measured by utilizing the next eq.:

$$\Delta H^* = E_a^* - RT$$

$$\Delta S^* = (\Delta H^* - \Delta G^*) / T$$
(9)
(10)

$$\Delta S = (\Delta H - \Delta G)/T \tag{10}$$

The +ve signs ( $\Delta$ H) reflect the endothermic corrosion process of the CS. The  $\Delta$ S has -ve sign in the with and without SBE indicates that the activated complex in the rate-determining step prefers association rather than dissociation, lead to lower in disorder[40].



Figure 3: Arrhenius diagrams of CS corrosion without and with various doses of SBE



Figure 4: log (k<sub>corr</sub>/T) vs (1000/T) of CS without and with various does of SBE

| [inh] | E*a             | $\Lambda H^*$   | - <b>A</b> S <sup>*</sup>             |
|-------|-----------------|-----------------|---------------------------------------|
| (ppm) | $(kJ mol^{-1})$ | $(kJ mol^{-1})$ | $(J \text{ mol}^{-1} \text{ K}^{-1})$ |
| Blank | 38.0            | 15.4            | 164.7                                 |
| 50    | 23.9            | 8.9             | 221.5                                 |
| 100   | 23.8            | 8.8             | 223.5                                 |
| 150   | 23.5            | 8.4             | 230.1                                 |
| 200   | 21.8            | 7.9             | 232.2                                 |
| 250   | 20.7            | 7.6             | 235.4                                 |
| 300   | 20.1            | 6.9             | 239.4                                 |

Table 4: Parameters of activation obtained from CS corrosion without and with various doses of SBE

#### 3.4. Tafel polarization (TP) tests

The TP diagrams for CS in 1.0 M HCl without and with various doses of the SBE at 25 °C are given in (Figure.5). The parameters obtained from TP are listed in Table (5). It is clear that the presence of SBE decreases both the anodic dissolution of CS and cathodic hydrogen discharge reactions. It is noted that the  $E_{corr}$  and Tafel slopes slightly changed by the addition of the extract, which indicates that this extract acts as mixed type one [41]. The results also showed that the slope of the anodic and the cathodic Tafel lines was exchange little on raising the dose of the SBE. This indicates that there is no change in the mechanism of protection with and without the presence of the extract. The higher data of Tafel slope can be an aspect to surface kinetic process rather the diffusion-controlled process [42].



Figure 5: TP diagrams for CS without and with various doses of SBE at 25°C

| [inh.]<br>ppm | -E <sub>corr</sub> ,<br>mV vs SCE | i <sub>corr</sub> ,<br>μA cm <sup>-2</sup> | $\beta_c,$<br>mV dec <sup>-1</sup> | $\beta_{a},$<br>m V dec <sup>-1</sup> | k <sub>corr</sub><br>mpy | θ     | %IE  |
|---------------|-----------------------------------|--|------------------------------------|---------------------------------------|--------------------------|-------|------|
| Blank         | 503                               | 152.0                                      | 185                                | 104                                   | 69.51                    |       |      |
| 50            | 502                               | 93.7                                       | 175                                | 45                                    | 42.8                     | 0.384 | 38.4 |
| 100           | 501                               | 65.0                                       | 165                                | 43                                    | 29.69                    | 0.572 | 57.2 |
| 150           | 500                               | 50.2                                       | 132                                | 70                                    | 22.95                    | 0.669 | 66.9 |
| 200           | 502                               | 41.0                                       | 134                                | 71                                    | 18.75                    | 0.730 | 73.0 |
| 250           | 506                               | 23.1                                       | 122                                | 71                                    | 10.53                    | 0.848 | 84.8 |
| 300           | 496                               | 15.1                                       | 133                                | 82                                    | 7.21                     | 0.910 | 91.0 |

Table 5: Effect of SBE dose on corrosion parameters of CS in HCl at 25°C

#### 3.5. Electrochemical impedance spectroscopy (EIS) tests

EIS measurements have been carried out at 298 K. Nyquist diagrams show a single semicircle. Impedance data are examined utilizing the circuit in (Figure.8); in which  $R_s$  signifies the resistance of theelectrolyte,  $R_{ct}$  is the charge-transfer resistance and (CPE) is the constant phase element. According to Mansfeld and Hsu the ability of improvement to its real data is measured from eq. (11):

$$C_{dl} = Yo (\omega_{max})^n$$

(11)

where Yo is the coefficient of CPE,  $\omega$  a maximum frequency and n is the CPE exponent (phase shift). The data obtained from fitted spectra are record in Table (6). From this table the data of R<sub>s</sub> are very slight related to the data of R<sub>ct</sub>. Also; the data of R<sub>ct</sub> were increased, due to the increase thickness of the adsorbed layer and the measured C<sub>dl</sub> data lowered by raising the extract doses, due to the replacement of water molecules on a CS

surface by the extract molecules. The great  $R_{ct}$  data are usually linked with the lower corroding system [43]. The %IE, measured by EIS results, showed the same trend as those obtained from TP tests. The variance of %IE from two tests may be qualified to the various surface status of the electrode in two tests [44].

| [inh.] | $C_{dl} \times 10^{6}$ | $R_{ct}$<br>$\Omega \text{ cm}^{-2}$ | θ     | %IE  |
|--------|------------------------|--------------------------------------|-------|------|
| 0      | 91.2                   | 58.1                                 |       | -`-  |
| 50     | 48.4                   | 83.0                                 | 0.435 | 43.5 |
| 100    | 39.3                   | 177.1                                | 0.672 | 67.2 |
| 150    | 31.2                   | 199.1                                | 0.708 | 70.8 |
| 200    | 29.2                   | 340.4                                | 0.829 | 82.9 |
| 250    | 17.3                   | 605.2                                | 0.904 | 90.4 |
| 300    | 13.3                   | 959.5                                | 0.942 | 94.2 |

Table 6: The obtained data from EIS for CS corrosion without and with various doses of SBE at 25°C



Figure 6: The Nyquist diagrams for CS corrosion with and without various doses of SBE at 25°C



Figure 7: Bode diagrams for CS corrosion without and with various doses of SBE at 25°C



Figure 8: Circuit used to fit the EIS data

#### 3.6. Electrochemical frequency modulation (EFM) Tests

EFM is a nondestructive corrosion test that can fast measure the corrosion current data without prior information of Tafel slopes, and with only a little polarizing signal [45]. Figure. 9 demonstrates the EFM spectra of the current response of CS in 1.0 M HCl. The EFM data of CS in 1.0 M HCl acid solution including (50-300 ppm) of the studied inhibitors are presented in (Figure.10). The EFM data have examined to measure  $i_{corr}$ ,  $\beta_a$ ,  $\beta_c$  and the causality factors (CF-2 and CF-3) which have listed in Table (7). From this Table,  $i_{corr}$  has been lowered and %IE rises with raising SBE doses. The exchange of values of  $\beta_a$  and  $\beta_c$  data was also little demonstrating that the presence of SBE given the same mechanism [46]. The causality factors, CF-2 and CF-3 obtained from EFM have been near to theoretical data of 2 and 3 consistently, showing that the obtained data had verified and excellent value. The % IE <sub>EFM</sub> was measured as in eq (3)







Figure 10: EFM spectra for CS in 1.0 M HCl without and with various doses of SBE at 25°C

| [inh]<br>ppm | i <sub>corr</sub> .<br>μA cm <sup>-2</sup> | $\beta_a$ mV dec <sup>-1</sup> | $-\beta_c$ mV dec <sup>-1</sup> | CF-2  | CF-3  | k <sub>corr</sub><br>mpy | θ     | %IE  |
|--------------|--|--------------------------------|---------------------------------|-------|-------|--------------------------|-------|------|
| Blank        | 700.4                                      | 104                            | 124                             | 1.063 | 2.742 | 320.00                   |       |      |
| 50           | 328.3                                      | 75                             | 130                             | 1.934 | 2.511 | 150.00                   | 0.531 | 53.2 |
| 100          | 201.6                                      | 81                             | 103                             | 1.243 | 3.231 | 92.12                    | 0.712 | 71.2 |
| 150          | 88.63                                      | 80                             | 80                              | 1.487 | 2.678 | 40.5                     | 0.873 | 87.3 |
| 200          | 58.55                                      | 90                             | 114                             | 1.912 | 3.221 | 26.76                    | 0.916 | 91.6 |
| 250          | 55.63                                      | 61                             | 65                              | 1.125 | 3.411 | 25.42                    | 0.920 | 92.0 |
| 300          | 30.94                                      | 83                             | 105                             | 1.386 | 2.833 | 14.14                    | 0.955 | 95.5 |

Table 7: EFM data for CS corrosion in 1.0 M HCl including various doses of SBE at 25°C

# *3.7. Surface characterization studies*

# 3.7.1. SEM analysis

The CS material which is cut into pieces were polished and immersed in the test solution for 24 hour acid solution. The test sample was prepared utilizing bi-distilled water. The specimens were dipped into 1.0 M HCl, which contains the extract with 300 ppm concentration and then the specimens were removed from the beaker, dried and kept in desiccators until analyzed by Scanning Electron Microscope (SEM) for surface morphological studies. The micrograph is shown in the (Figure. 11) which showed that the polished specimens were immersed in the blank solution of 1.0 M HCl and in the acids containing SBE which associated with polishing scratches. This result improves the surface coating of the CS so that there is a lower in the contact among CS and the aggressive solution.



**Figure 11(a-c)**: SEM morphology of CS surface (a) before of dipping in 1.0 M HCl ,(b) after 24 hours of dipping in 1.0 M HCl and (c)after 24 hours of dipping in 1.0 M HCl +300 ppm of SBE at 25°C

# 3.7.2. EDX examination

The EDX spectra were utilized to measure the existing elements on the surface of CS and afterward 24 hrs of coverage in the unprotected and protected 1.0 M HCl. (Figure. 12) demonstrates the results of EDX on the CS in the absence of the acid and SBE inhibitor usage (Figure.12 a), CS in existence in 1.0M HCl (Figure12.b) and CS with IM HCl and 300 ppm of SBE (Figure.12c). It is observed that attendance (C and O) peak in the EDX image for coins that immersion to the SBE inhibitor. (Figure 12c) show compositions of distinguished elements on the CS surface designates that the extract molecules are powerfully adsorbed on the CS forming a bond (Fe – SBE), thus inhibits the surface versus the corrosion. Table (8) showed that (weight %) of the adsorbed atoms on the surface by the extract, confirming the adsorption process take place and surface coverage due to the carbon and oxygen atoms.



**Figure 12:** EDX image on CS in existence and nonexistence of 300 ppm of SBE for 1 day dipping in 1.0 M HCl. (a) pure CS surface (b) after 24 hrs dipping in 1.0 M HCl (c) 24 hrs dipping in 1.0 M HCl +300 ppm of SBE

| Weight%    | Fe    | С    | 0    |
|------------|-------|------|------|
| Metal free | 79.09 | 2.09 |      |
| Blank      | 66.19 | 2.81 | 3.61 |
| SBE        | 78.68 | 8.9  | 4.51 |

Table 8: Weight % of CS after 24h of dipping in 1.0 M HCl without and with the optimum doses of the SBE

# 3.7.3. Atomic force microscopy (AFM) tests

Investigation of the images that given the roughness of the CS surface over area scale of  $1.11\mu m$ . The 3D AFM of CS surface existence and nonexistence of SBE inhibitor are displayed in Figure. (13 a, b). The roughness of CS coins after inundation in 1.0M HCl is up to 497 nm (Figure. 13a), while in the attendance of SBE inhibitor , the roughness lesser to 131 nm (Figure. 13b)as presented in able 9. It indications that the CS coins in attendance of SBE are more compact and uniform, so it can casually control CS surface from corrosion. This approves that the control surface is smoother than the unhindered surface. The CS smoothness is due to the enlargement of a coating film on the surface.



Figure 13: AFM 3D images of CS (a) with 1.0 M HCl for 24 hrs (b) with 1.0 M HCl inclosing 300 ppm SBE for 24 hrs

| Parameters | The roughness average (Sa) | The root mean square (Sq) | The peak height(Sp) |
|------------|----------------------------|---------------------------|---------------------|
| А          | 497                        | 810.95                    | 1830.20             |
| В          | 131.22                     | 179.19                    | 1318.3              |

**Table 9:** AFM parameters for CS (a) with 1.0 M HCl for 24 hrs. (b) with 1.0 M HCl containing 300 ppm SBE for 24 hrs

# 3.7.4. FTIR examination

FTIR spectroscopy displays interesting features such as a high signal to notice ratio, high sensitivity and selectivity, accuracy, mechanical simplicity, short analysis time and small amount of sample required for the analysis. (Figure.14), It is detected that there are moves in the frequencies. It was found that (O-H) stretch at 3380 cm<sup>-1</sup>was moves to 3365 cm<sup>-1</sup>, the C = C stretch at 1640 cm<sup>-1</sup> was lifted to 1683 cm<sup>-1</sup>, signifying that there is an interaction among the SBE and CS surface. Other functional groups were absent signifying that the adsorption of the SBE on the CS might have happened between the disappeared bonds. It can be affirmed that the functional groups have coordinated with Fe<sup>+2</sup> formed on the metal resulting in the formation of Fe<sup>+2</sup> SBE complex on the CS ,which encourages the control of the CS coins.



**Figure.14.** FTIR Spectrum of pure SBE and corrosion products of CS after the ML test in presence of 300 ppm of SBE at 25°C

# Conclusions

The SBE showed excellent corrosion inhibition property versus CS corrosion in 1.0 M HCl solution. IE's are associated to dose, temperature and chemical composition of the investigated SBE. Commonly, %IE rises when the dose of the extract rises and at lower temperatures. SBE affected both anodic and cathodic reactions, so they defined as a mixed kind inhibitor. Adsorption of SBE on the CS surface follows Temkin isotherm. EIS calculation clarified that the corrosion process was mainly charge transfer controlled and no change in the mechanism of corrosion due to the presence of SBE inhibitor to 1.0 M HCl solution

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