Adsorption and corrosion inhibition of mild steel in acidic media by expired pharmaceutical drug

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Abstract: The inhibitive action of an examined expired Ambroxol drug on the corrosion of mild steel in 1 M HCl and 1 M H2SO4 acid medium has been studied by weight loss and electrochemical techniques. The weight loss techniques result was discussed. The inhibition efficiency increases with increasing the concentration of the inhibitor. Electrochemical studies data support that examined expired drug is an efficient inhibitor for mild steel corrosion. The adsorption of the examined drug obeys Langmuir’s adsorption isotherm. Polarization studies indicate that this inhibitor acts as a mixed type inhibition. The various thermodynamic parameters were calculated and discussed. The protective film formed on the surface was confirmed by SEM. The data collected from the studied techniques are in good agreement to confirm the ability of using expired Ambroxol drug as corrosion inhibitor for mild steel in both acid media.

Keywords: mild steel; polarization; SEM; weight loss; acid corrosion

1. Introduction

Mild steel is an important material widely used in various industries and used in most of the automobiles, pipes and chemical industries. Hydrochloric acid and sulphuric acid are the medium generally being used for pickling of mild steel (Abdallah, 2002; Al-Amiery, Kadhum, Alobaidy, Mohamad, &...
Generally, acids cause damage to the substrate, because of their corrosive nature. Thus, protecting mild steel from corrosion is the most important problem. Several methods were used to decrease the corrosion of metals in acidic medium, but the use of inhibitors is most commonly used. Hence, the corrosion process may be censored by the protective film of inhibitor on the metal surface. A large number of scientific studies have been devoted to the subject of corrosion inhibitors for mild steel in acidic media. Majority of the organic inhibitors for the corrosion of steel in different aggressive media are the organic compounds containing N, S, O and P atoms or N-hetero cyclic compounds with polar groups. These groups of atoms or bonds facilitate electronic interactions between organic corrosion inhibitors and metal surface thereby aid adsorption of the inhibitors onto metal surface.

The quest for eco-friendly compounds as corrosion inhibitors has shifted research focus to exploring potential application of expired drugs as corrosion inhibitors in the past few years (Ahamad & Quraishi, 2010; Fouda et al., 2008; Geethamani & Kasthuri, 2015; Hosseini, Mertens, & Arshadi, 2003; Khan & Quraishi, 2010; Prabhu, Shanbhag, & Venkatesha, 2007; Quraishi & Rawat, 2000; Quraishi, Sardar, & Jamal, 2001; Umoren & Ebenso, 2007; ZhaoT & Mu, 1999).

Recently, many expired drugs have been reported to be very effective corrosion inhibitors for the protection of mild steel in acidic media (Ahamad Khan, Ansari, & Quraishi, 2011; Hari Kumar & Karthikeyan, 2013; Kumar & Karthikeyan, 2012; Larabi, Harek, Traisnel, & Mansri, 2004; Magaji et al., 2012; Singh & Quraishi, 2010; Singha, Singh, & Quraishi, 2010) to promote eco-friendly environment. In this study, the inhibitive effect of expired Ambroxol drug on the corrosion of mild steel was investigated using weight loss and electrochemical method. The literature report on the studies of corrosion inhibition effect on Ambroxol on mild steel in acidic media was reported in our earlier paper (Geethamani & Kasthuri, 2015). Hence, attempts are made to utilize the expired Ambroxol drug as an anticorrosion agent on mild steel in sulphuric acid and hydrochloric acid medium.

2. Materials and methods

Solution of 1 M concentration of HCl and H2SO4 was prepared from Analar grade. The composition of mild steel has been analysed using vacuum emission spectrometer DV-4. The composition of mild steel has found to be 0.03% carbon, 0.25% manganese, 0.015% silicon, 0.003% phosphorus and the remainder iron. The commercially available cold rolled mild steel sheets were machined into strips of rectangular size 5 × 1 × 0.2 cm containing a hole at one end of the coupons for easy hooking. These specimens were polished with different grades of emery paper, degreased with acetone, washed with double-distilled water and properly dried.

2.1. Analytical methods

2.1.1. Weight loss method

The pre-treated specimen’s initial weights were noted accurately and were fully immersed in 100 ml of the experimental solution (in triplicate) of 1 M HCl and H2SO4 acid with and without different concentrations (1.0–11.0% (v/v)) of the inhibitor with the help of glass hooks at different time intervals (0.5, 2, 4, 6, 8 and 24 h) and temperature (303, 313, 333 and 343 K). After the exposed period, the specimen was removed, dried and weighed. From the weight loss, the inhibition efficiency (IE), surface coverage (θ) and corrosion rate (mpy) were calculated using the formula given in our earlier paper (Ahamad Khan et al., 2011; Geethamani & Kasthuri, 2015; Geethamani, Kasthuri, & Aejitha, 2014b).

2.1.2. Electrochemical method

The electrochemical measurements were carried out in a conventional three-electrode cell consisting platinum electrode as auxiliary electrode, saturated calomel electrode as reference electrode and mild steel as working electrode. A time interval of 30 min was given for each experiment to attain the steady-state open-circuit potential. The three-electrode set-up was immersed in acid solutions in the absence and presence of inhibitor at room temperature. For the measurements of impedance, the cell used was same as that used for potentiodynamic polarization. An AC potential
of 10 mV was super imposed on the study of open-circuit potential. Nyquist plots were obtained from the results of these experiments. The charge transfer resistance ($R_{ct}$) values were obtained from the plots of $Z'$ versus $Z''$ and the double-layer capacitance $C_d$ values were obtained from the following Equation (1),

$$C_d = \frac{1}{2\pi f_{max} R_{ct}}$$

where $C_d$ is the double-layer capacitance; $R_{ct}$ is the charge transfer resistance; $f_{max}$ is the frequency at $Z''$ value maximum.

Besides, the above method, the inhibition efficiencies were obtained from $R_p$ and $R_{ct}$ values as follows:

$$\text{Inhibition Efficiency (IE \%)} = \frac{R_{p(i)} - R_p}{R_{p(i)}} \times 100$$

where $R_{p(i)}$ and $R_p$ are the charge transfer resistance in the presence and absence of inhibitor.

2.1.3. Surface examination studies
The surface morphology of corrosion product on mild steel sample in 1 M HCl and 1 M H$_2$SO$_4$ in the absence and presence of 9.0% (v/v) of examined expired Ambroxol was studied. After the immersion period, sample was dried and analysed by a scanning electron microscope.

3. Results and discussion

3.1. Weight loss studies

3.1.1. Effect of concentration of inhibitor and time of immersion
The IE obtained from weight loss method in both 1 M HCl and H$_2$SO$_4$ in the absence and presence of various concentrations of the inhibitor are summarized in Table 1. It illustrates that the IE increased with an increase in the concentration of the inhibitor at 9.0%.

3.1.2. Performance of the inhibitors in 1 M HCl
The maximum IE was noticed at a concentration 9.0% of the inhibitor is 94.03%. The inhibitor efficiency increases with an increase in the immersion time, since more adsorption takes place on the

| Concentration of the inhibitor (v/v %) | Inhibition efficiency of the expired Ambroxol drug |
|--------------------------------------|---------------------------------------------------|
|                                      | In 1 M HCl                                      | In 1 M H$_2$SO$_4$ |
|                                      | $\frac{1}{2}$ h | 2 h | 4 h | 6 h | 8 h | 24 h | $\frac{1}{2}$ h | 2 h | 4 h | 6 h | 8 h | 24 h |
| 1.0                                  | 34.97       | 40.46 | 45.22 | 39.53 | 34.98 | 24.84 | 35.28 | 47.41 | 53.13 | 58.01 | 53.45 | 44.27 |
| 2.0                                  | 39.61       | 49.92 | 50.80 | 45.29 | 40.84 | 30.40 | 42.53 | 52.59 | 58.95 | 63.49 | 59.88 | 52.06 |
| 3.0                                  | 43.82       | 55.14 | 57.30 | 51.57 | 48.21 | 39.43 | 43.57 | 56.47 | 63.77 | 68.36 | 63.65 | 55.81 |
| 4.0                                  | 48.03       | 61.01 | 64.40 | 57.33 | 53.50 | 49.39 | 48.23 | 59.70 | 67.38 | 73.02 | 67.34 | 61.91 |
| 5.0                                  | 53.65       | 65.25 | 72.58 | 60.99 | 57.45 | 53.91 | 56.73 | 60.67 | 70.69 | 78.09 | 71.25 | 67.55 |
| 6.0                                  | 56.46       | 71.43 | 77.48 | 68.59 | 60.10 | 59.41 | 58.06 | 62.26 | 74.71 | 83.77 | 74.32 | 70.14 |
| 7.0                                  | 59.27       | 76.84 | 82.88 | 74.08 | 63.56 | 61.03 | 60.91 | 69.33 | 77.22 | 86.82 | 78.43 | 75.07 |
| 8.0                                  | 62.08       | 80.10 | 88.74 | 80.15 | 68.24 | 65.76 | 62.72 | 74.84 | 81.83 | 89.05 | 81.65 | 78.28 |
| 9.0                                  | 64.89       | 84.34 | 94.03 | 88.05 | 81.27 | 76.26 | 68.35 | 80.07 | 84.64 | 95.54 | 84.60 | 81.10 |
| 10.0                                 | 57.87       | 78.14 | 88.37 | 82.60 | 73.53 | 66.42 | 57.80 | 76.83 | 81.03 | 85.35 | 75.85 | 73.49 |
| 11.0                                 | 46.63       | 69.98 | 80.30 | 75.45 | 61.32 | 44.41 | 51.33 | 73.78 | 77.62 | 79.70 | 67.24 | 60.00 |
metal surface. Optimum IE is reached in 4 h and further increase in time did not cause any appreciable change in the performance of inhibitor.

3.1.3. Performance of Am inhibitor in 1 M H₂SO₄
It was found that inhibitor efficiency rise in concentration of the inhibitor from 1.0 to 9.0% (v/v). At the optimum concentration of 9.0% (v/v), the acid dissolution of the inhibitor is 95.54%. Since more adsorption takes place on the metal surface, the inhibitor efficiency increases with increasing immersion time. It was found that the optimum IE is reached in 6 h and further increase in time did not cause any appreciable change in the performance of the inhibitor. This result indicated that the expired Ambroxol is excellent corrosion pickling inhibitor (Umoren & Ebenso, 2007).

3.1.4. Effect of temperature
The influence of temperature on the inhibitor in 1 M HCl and 1 M H₂SO₄ was investigated in the temperature range, 303–343 K, for 30 min of immersion and the results are presented in Figure 1. From the figure, the IE increased with increasing temperature up to 333 K at 9.0% (v/v) and decreased thereafter, indicating that the inhibitor was more effective at higher temperature up to 333 K at 9.0% (v/v) concentration. It indicates that the maximum IE of 93.35 and 92.00% was noticed at a concentration 9.0% of the inhibitor in 1 M HCl and 1 M H₂SO₄ medium at 333 K, respectively. From the data, it can be inferred that the protective layer formed on mild steel surface, due to adsorption of the inhibitor. This may be explained as adsorption and desorption of inhibitor molecules which continuously occur at the metal surface and equilibrium exists between these two processes at a particular temperature (Quraishi & Rawat, 2000). Considering this increase in efficiency with an increase in the temperature suggests chemical adsorptions of the inhibitor over the corroding surface.

3.1.5. Thermodynamic consideration
The activation energy at different concentrations of the inhibitor in 1 M HCl and 1 M H₂SO₄ is calculated by plotting log CR vs. 1/T (Figure 2). The calculated values of activation energy (Eₐ) and thermodynamic data such as change in free energy of adsorption (ΔG_ads), the enthalpy of adsorption (ΔH) and the entropy of adsorption (ΔS) for mild steel in 1 M HCl and 1 M H₂SO₄ with and without inhibitor.
Table 2. Thermodynamic data for mild steel in 1 M HCl and 1 M H$_2$SO$_4$ in the presence and absence of acid solution of the inhibitor at 303–343 K

| Concentration of the inhibitor (v/v %) | $E_a$ (kJ/mol) | $\Delta G$ (kJ/mol) | $\Delta H$ (kJ/mol) | $\Delta S$ (kJ/mol) | $E_a$ (kJ/mol) | $\Delta G$ (kJ/mol) | $\Delta H$ (kJ/mol) | $\Delta S$ (kJ/mol) |
|---------------------------------------|----------------|---------------------|---------------------|---------------------|----------------|---------------------|---------------------|---------------------|
|                                       | 303 K          | 313 K               | 323 K               | 333 K               | 343 K          | 303 K               | 313 K               | 323 K               | 333 K               | 343 K               |
| Blank                                 | 60.98          | -                   | -                   | -                   | -               | 122.87              | -                   | -                   | -                   | -                   |
| 1.0                                   | 55.85          | 13.33               | 15.51               | 16.50               | 18.03           | 16.85               | 14.80               | 0.0955              | 116.42              | 14.97               | 15.81               | 17.22               | 18.62               | 17.08               | 9.979               | 0.0823              |
| 2.0                                   | 55.11          | 12.79               | 14.78               | 15.51               | 16.50           | 15.89               | 10.54               | 0.0794              | 116.06              | 13.90               | 14.93               | 15.96               | 17.48               | 15.66               | 9.214               | 0.0763              |
| 3.0                                   | 54.16          | 12.20               | 14.48               | 15.22               | 16.07           | 15.40               | 11.12               | 0.0799              | 116.55              | 13.45               | 14.66               | 15.42               | 16.69               | 14.93               | 7.580               | 0.0694              |
| 4.0                                   | 53.09          | 12.01               | 14.53               | 15.28               | 15.97           | 15.26               | 11.07               | 0.0795              | 117.28              | 13.31               | 14.60               | 15.22               | 16.38               | 14.53               | 6.064               | 0.0639              |
| 5.0                                   | 52.42          | 11.71               | 14.95               | 15.76               | 16.41           | 15.21               | 12.54               | 0.0847              | 117.20              | 13.34               | 14.48               | 15.32               | 16.35               | 14.28               | 4.714               | 0.0596              |
| 6.0                                   | 49.68          | 12.04               | 15.07               | 15.81               | 16.52           | 15.55               | 12.39               | 0.0848              | 118.03              | 13.53               | 14.88               | 15.49               | 16.51               | 14.19               | 3.484               | 0.0562              |
| 7.0                                   | 47.13          | 11.94               | 15.54               | 16.23               | 17.16           | 15.76               | 14.62               | 0.0927              | 116.23              | 13.61               | 14.92               | 15.98               | 17.15               | 14.10               | 5.174               | 0.0620              |
| 8.0                                   | 43.94          | 11.90               | 15.58               | 16.24               | 17.25           | 16.24               | 17.99               | 0.1035              | 113.96              | 13.47               | 14.80               | 16.07               | 17.67               | 14.21               | 8.809               | 0.0735              |
| 9.0                                   | 41.42          | 11.91               | 15.97               | 16.79               | 17.91           | 16.46               | 19.91               | 0.1106              | 109.05              | 13.41               | 14.85               | 16.29               | 18.15               | 14.48               | 12.574              | 0.0857              |
| 10.0                                  | 48.25          | 10.89               | 14.71               | 15.44               | 16.20           | 14.45               | 13.41               | 0.0859              | 116.19              | 12.45               | 14.07               | 14.35               | 15.90               | 12.88               | 5.177               | 0.0582              |
| 11.0                                  | 47.94          | 9.51                | 13.54               | 14.29               | 15.24           | 13.23               | 16.31               | 0.0913              | 118.19              | 11.55               | 12.88               | 13.60               | 14.52               | 11.58               | 3.052               | 0.0482              |
are listed in Table 2. From Table 2, the $E_a$ values of protected mild steel are lower than unprotected mild steel in both the acidic media due to the adsorption of inhibitor molecules on the metal surface (Larabi et al., 2004; Quraishi & Sudheer, 2011). The negative value of free energy of adsorption ($\Delta G_{ads}$) indicates the spontaneous adsorption of the inhibitor on mild steel (Singh & Quraishi, 2010). The positive sign of enthalpy indicates the endothermic reaction suggesting that a more energy was needed for the activated state and in the high temperature the inhibitor highly adherent to metal surface. The change in entropy values found to be greater than zero suggests that the reaction is irreversible and clearly says that adsorption followed desorption takes place, i.e. the complete desorption of the inhibitor is not possible (Geethamani, Kasthuri, & Aejitha, 2015; Singh & Shukla, 2011a).

### 3.1.6. Adsorption consideration

Assuming that, the corrosion inhibition was caused by the adsorption of the tested pharmaceutical compound, and the values of surface coverage for different concentrations of Am inhibitor in 1 M HCl and 1 M $H_2SO_4$ were evaluated from weight loss and it was observed that $\theta$ values increased with increasing the concentration of the inhibitor Am. The establishment of adsorption isotherm indicates the nature of the metal–inhibitor interaction. For the current study, attempts are made to fit the adsorption isotherm with various isotherms such as Langmuir, Freundlich and Temkin adsorption isotherms. Among the various isotherm studies, the Langmuir isotherm was near to unity (Hari Kumar & Karthikeyan, 2013). This indicates that the inhibitor was strongly adsorbed on the metal surface. Figure 3 shows the Langmuir adsorption isotherm. The plot of $\theta$ vs. log $C$ yields a straight line. It is observed that although these plots are linear, the gradients are never unity, contrary to what is expected for ideal Langmuir adsorption isotherm equation.

![Langmuir adsorption isotherm plot for the different concentrations of the inhibitor on mild steel in 1 M HCl and 1 M $H_2SO_4$ at 303 and 333 K.](image)

### Table 3. Potentiodynamic polarization (Tafel) parameters for the corrosion of mild steel in 1 M HCl and 1 M $H_2SO_4$ containing with and without inhibitor

| Acid medium | Concentration (v/v %) | $-E_{corr}$ (mV) | $I_{corr}$ (mA/cm$^2$) | $b_a$ (mV/dec) | $b_c$ (mV/dec) | $R_p$ (Ωcm$^2$) | IE (%) |
|-------------|----------------------|-----------------|------------------------|----------------|----------------|-----------------|--------|
| 1 M HCl     | Blank                | 502.9           | 0.412                  | 83             | 125            | 67.03           | –      |
|             | 2.0                  | 490.5           | 0.239                  | 72             | 142            | 110.2           | 39.17  |
|             | 5.0                  | 489.8           | 0.214                  | 68             | 141            | 135.7           | 50.60  |
|             | 9.0                  | 491.4           | 0.167                  | 65             | 143            | 169.8           | 60.52  |
| 1 M $H_2SO_4$ | Blank               | 522.9           | 0.896                  | 81             | 119            | 29.81           | –      |
|             | 2.0                  | 495.8           | 0.375                  | 69             | 149            | 71.81           | 58.49  |
|             | 5.0                  | 502.1           | 0.348                  | 67             | 130            | 83.8            | 64.43  |
|             | 9.0                  | 528.8           | 0.262                  | 64             | 670            | 94.98           | 68.61  |
3.2. Electrochemical studies

3.2.1. Potentiodynamic polarization studies

Electrochemical corrosion kinetic parameters such as corrosion potential \((E_{\text{corr}})\), corrosion current \((I_{\text{corr}})\), anodic and cathodic Tafel slopes \((b_a\) and \(b_c)\) and percentage of IE for the corrosion of mild steel in 1 M HCl and H_2SO_4 at 30°C in the absence and presence of different concentrations of the inhibitor are given in Table 3 and its corresponding polarization curves are shown in Figure 4. This study revealed that the corrosion current density \((I_{\text{corr}})\) markedly decreased with the addition of the inhibitor and corrosion potential shifts to less negative values upon addition of the inhibitor.

![Figure 4. Potentiodynamic polarization curves for mild steel in 1 M HCl and 1 M H_2SO_4 in the absence and presence of different concentrations of extract.](image)

![Figure 5. Impedance diagram for mild steel in 1 M HCl and 1 M H_2SO_4 in the presence and absence of different concentrations of the inhibitor.](image)

| Acid medium | Concentration (v/v %) | \(R_{\text{ct}}\) (\(\Omega\)cm\(^2\)) | \(C_{\text{dl}}\) (\(\mu\)F/cm\(^2\)) | IE (%) |
|-------------|-----------------------|---------------------------------|---------------------------------|--------|
| 1 M HCl     | Blank                 | 25.67                           | 628                             | -      |
|             | 2.0                   | 46.61                           | 531                             | 44.93  |
|             | 5.0                   | 51.71                           | 508                             | 50.36  |
|             | 9.0                   | 67.47                           | 464                             | 61.95  |
| 1 M H_2SO_4 | Blank                 | 19.12                           | 358                             | -      |
|             | 2.0                   | 35.13                           | 385                             | 45.57  |
|             | 5.0                   | 48.26                           | 322                             | 60.38  |
|             | 9.0                   | 61.53                           | 289                             | 68.93  |
Moreover, the values of anodic and cathodic Tafel slopes (ba and bc) are slightly changed indicating that this behaviour reflects the acid dissolution of the inhibitor ability to inhibit the corrosion of mild steel in 1 M HCl and H₂SO₄ via adsorption of its molecules on both anodic and cathodic sites and consequently, it act through mixed mode of inhibition (Ahmad Khan et al., 2011; Kumar & Karthikeyan, 2012; Magaji et al., 2012).

3.2.2. Electrochemical impedance studies
Impedance spectra (Nyquist plots) of mild steel in 1 M HCl and H₂SO₄ containing various concentrations (2.0, 5.0 and 9.0 (v/v %)) of the inhibitor at 30°C are shown in Figure 5. Nyquist plots contain depressed semicircles with the centre under the real axis. The size of the semicircle increases with the inhibitor concentration, indicating the charge transfer process as the main controlling factor of the corrosion of mild steel (Singha et al., 2010). It is apparent from the plots that the impedance of the inhibited solution has increased with an increase in the concentration of the inhibitor. The experimental results of EIS measurements for the corrosion of mild steel in 1 M HCl and 1 M H₂SO₄ in the absence and presence of inhibitor are given in Table 4. It can be concluded that the charge transfer resistance (Rc) value increased with an increase in the concentration of the inhibitor, where as values of the double-layer capacitance (Cdl) of the interface start decreasing, with an increase in the inhibitor concentration, which is most probably due to the decrease in local dielectric constant.
and/or increase in thickness of the electrical double layer (Geethamani, Kasthuri, & Aejitha, 2014a; Umoren, Obot, & Gasem, 2014).

3.2.3. Morphology examination of mild steel
The photographs for mild steel immersed in 1 M HCl and 1 M H₂SO₄ acid with and without inhibitor are given in Figure 6(a–e). From the pictures, the attacks in the presence of inhibitor in acid are less in comparison with the blank acid because of forming a passive layer on the metal surface. This layer acts as a barrier against corrosive ions on the surface of mild steel and electrochemical corrosion rate will be eventually decreased (Abdallah & Zaafarany, 2012; Abdel Hameed, 2011; Nicolae, Ordodi, & Borza, 2012). The depth of surface corroded due to the exposure of mild steel to acid is well visible with shallow pits, pores and cracks. It was also noticed that the corrosion products formed are found to deposit as separate layers in cluster.

3.2.4. Mechanism
The inhibitive action of organic compounds depends of their structure and functional groups, nature of the metal and aggressive medium. Mild steel corrosion inhibition suggested to be attributed to adsorption of the inhibitors at the electrode/solution interface, the extent of adsorption of an inhibitor depended on the nature of the metal, the mode of adsorption of the inhibitor and the surface conditions. Adsorption on metal surface was suggested to be via the active centres attached to the tested drugs and relies on their charge density. Nitrogen atoms donate lone pairs of electrons to the mild steel surface forming coordinate bond (El-Desoky, Ahmed, & Ali, 2015).

The inhibitory action of Ambroxol drug may be due to any or combination of the following mechanisms: (1) electrostatic interactions between protonated nitrogen atoms and already adsorbed oxygen atoms; (2) coordination due to donor–acceptor interactions between the unshared electron pairs of oxygen, fluorine and possibly nitrogen; the π-electrons from the aromatic rings may also interact with the vacant d-orbital of the atoms of the metal at the interface; (3) since the molecular weight of the compound is large, inhibition may also be effected by hindering of attacks by aggressive species due to wider surface covered by large molecules of the inhibitor.

3.2.5. Comparison of IE of the inhibitor in acid media
The IE obtained by the weight loss measurements, polarization and electrochemical impedance techniques are almost similar. Hence, the expired Ambroxol drug can be effectively used as an inhibitor for static and dynamic conditions. The results obtained from the weight loss measurements and electrochemical studies in 1 M HCl and 1 M H₂SO₄ on mild steel suggest that this inhibitor is a good corrosion pickling inhibitor. But the IE in 1 M HCl is higher than that in 1 M H₂SO₄ medium (El-Desoky et al., 2015; Singh & Shukla, 2011b). This is because evolution of hydrogen is more in 1 M H₂SO₄ medium which accompanies corrosion. This may not allow the establishment of adsorption process sufficiently and rapidly resulting in decrease in IE. Another reason is chloride ion being less hydrated than sulphate ion and strongly adsorbed on the metal surface and favours the synergistic effect on the mild steel surface in 1 M HCl medium. Hence, it may be concluded that expired Ambroxol drug exhibits good IE on the corrosion of mild steel in 1 M HCl than in 1 M H₂SO₄ (Saratha et al., 2009).

4. Conclusion

• The expired Ambroxol drug acts as good and efficient corrosion inhibitor for the corrosion of mild steel in 1 M HCl and 1 M H₂SO₄ acid medium.
• The IE values increase with an increase in the inhibitor’s concentration.
• The IE increases with temperature; it indicates that it acts as an effective inhibitor at higher temperature also.
• The negative Gibbs free energy values indicate that the adsorption of inhibitor on surface is a spontaneous process.
• The adsorption of the inhibitor on mild steel obeys Langmuir adsorption isotherm.
• Polarization studies indicate that the inhibitor act as a mixed-type inhibitor.
• The FTIR results indicate the presence of a uniform film over the metal surface, which effectively protects from the corrosion.
• SEM reveals the formation of a smooth uniform surface on mild steel in the presence of the inhibitor which indicates the formation of a good protective layer on the metal surface.

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