Alkaloid of *Rhynchostylis retusa* as Green Inhibitor for Mild Steel Corrosion in 1 M H$_2$SO$_4$ Solution

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Abstract: Alkaloids are aromatic hydrocarbons with nitrogen as heteroelements in the ring structure that are responsible for bonding with the metal surface and help to reduce corrosion of metals such as mild steel (MS) in an acidic medium. In this study, the alkaloid of *Rhynchostylis retusa* (RR) was extracted by solvent extraction method and confirmed by chemical test as well as FTIR spectroscopic test. Extracted alkaloids were tested as green inhibitors for the MS corrosion in a 1.0 M H$_2$SO$_4$ solution. The inhibition efficiency (IE) of alkaloid extracts of RR was studied by the weight loss measurement method and electrochemical polarization method. Results showed that the maximum IE in the gravimetric method was 87.51% in 1000 ppm solution at 6 h immersion time. Open circuit potential (OCP) and potentiodynamic polarization results indicated that the extracted alkaloids acted as a mixed type of inhibitor. IE by polarization method was found to be 93.24% for the sample immersed for 6 h. The temperature effect study reveals that inhibitors can work only below 35 °C. Alkaloids of RR can be successfully extracted and used as corrosion inhibitors for MS in an acidic medium below 35 °C.

Keywords: mild steel; corrosion; alkaloids; green inhibitor; weight loss; polarization

1. Introduction

Mild steel (MS) is a versatile ferrous alloy with large applications because of its excellent mechanical properties [1–3]. It is used heavily to build a large number of infrastructures, buildings, and industries due to its ease of fabrication and low purchasing cost; however, MS corrosion is a serious matter of concern in acidic environments such as Petrochemical, chemical plants, and gasoline pipelines [4,5]. In addition, processes such as acid pickling, de-scaling, and cleaning of boilers cause extensive corrosion damage to the surface and mechanical properties of MS. Nevertheless, it is a difficult task for industries to protect MS from corrosion, leading to huge economic losses.

To prevent metal loss, various methods such as surface modification, alloy formation, and coatings are adopted [6]; however, such methods are applicable only for those MS which are utilized for infrastructures development, construction of buildings, and industries where it is not in contact with an acid environment. For the protection of MS used in acidic environments, the use of various inhibitors is more often used. Corrosion inhibitors may be either synthetic or natural, which, when added to such an environment, effectively decreases the corrosion rate. Interest in synthetic inhibitors is diminishing due to their toxicity toward human, animal, and aquatic life [7]. On the other hand, natural products as inhibitors are non-toxic, eco-friendly, easily available, and effective. Therefore, natural products are recently studied as corrosion inhibitors [8,9].
Plant extracts contain a large number of phytochemicals that are biodegradable. The inhibitive performances of plant extract are related to their phytochemicals such as alkaloids, tannins, flavonoids, carbohydrates, phenolics, proteins, etc. These metabolites usually bear polar functional groups as well as heteroelements such as Nitrogen, Sulphur, or Oxygen, and triple or double conjugate bonds which act as major adsorption centers [10]. Literatures reveal descriptions of numerous plants exhibiting inhibitive properties for MS in acidic medium such as the crude extracts of Lantana camara [1], Artemisia vulgaris [2], Aloe vera [11], Jasminum nudiflorum [12], Euphorbia royleana [13], Bamboo [14], Ficus hispida [15], Aniba rosaeodora [16], Mansoa alliacea [17], Ginkgo [18], Annona squamosal [19]. The inhibition efficiency of such reported plant extracts is very promising.

Among the heteroelements as corrosion inhibitors, the inhibition efficiency has to be followed the trend O < N < S < P [13]; however, natural products containing Sulphur and phosphorus-containing phytochemicals are hard to find. Therefore, natural product-based research on corrosion inhibitors focuses on nitrogen and oxygen-bearing phytochemicals. Alkaloids contain nitrogen in their structure and oxygen may have a chance to be in the structure of alkaloids in the form of the functional group. Rhynchostylis retusa (RR) has been reported as alkaloids containing plants in their rhizome, leaves, and flowers, Figure 1a,b [20,21]. Rhynchostylis retusa is a monopodial epiphyte, an exotic blooming orchid belonging to the family Orchidaceae that grows in the forest of lower Himalayan ranges. The epiphytic orchid usually grows on trees or shrubs without directly harming the hosts and plays a vital role in ecosystem functioning. It can be found in Nepal and South Asia [22]. In Nepal, commonly it is known as ‘Sunakhari or Sunghava’. It can tolerate the temperature from 3 °C to 31 °C. The flowering time is mainly from May to July. Nevertheless, Rhynchostylis has a very wide host range, Ficus religious is the most common host tree species [22].

![Figure 1](image)

Figure 1. (a) Rhynchostylis retusa in the host tree, (b) Rhynchostylis retusa showing Rhizome, leaf, and flower.

R. retusa is orchid species with beautiful flowers arranged in racemose, an inflorescence consisting of more than 100 pink–spotted white flowers, and has a robust stem of about 25 cm long [23]. It has medicinal properties due to the presence of different phytochemicals constituents such as dibenzyl derivatives, alkaloids, flavonoids, essential oils, etc. The extract of this plant is reported as medicine for the treatment of rheumatic disease, tuberculosis, epilepsy, blood dysentery, menstrual disorders, gout, asthma, skin diseases, external inflammations, and throat inflammation [23].
Therefore, in this work, alkaloid has been extracted from methanol extract of RR and the extracted alkaloid has been characterized and tested as a corrosion inhibitor for MS in 1 M H$_2$SO$_4$ solution using weight loss and electrochemical measurements.

### 2. Materials and Methods

#### 2.1. MS Sample Preparation

Mild steel sample A516 grade 60 (0.21–0.27% C, 0.13–0.45% Mn, 0.79–1.30% Si, 0.035% P, 0.035% S, and rest of Fe) in the form of a flat sheet was collected from the local market in Kathmandu, Nepal and cut into pieces of dimension (4 × 4 × 0.55) cm$^3$. Before experimenting, each coupon was polished with silicon carbide (SiC) paper of 100–1000 #grits. To ensure the dimension of coupons was measured with a digital Vernier caliper and washed with hexane. Washed coupons were ultrasonicated in ethanol, dried, and placed in a moisture-free desiccator (Experimental schematics are shown in Scheme 1).

**Sample Collection**

**Grinding Sample to Powder Form**

**Extraction of Alkaloid**

**Alkaloid as Inhibitor for Weight loss measurement**

**Alkaloid as Inhibitor for Electrochemical Measurement**

**Concentration Effect**

**Temperature Effect**

**Immersion Time Effect**

**OCP Measurement**

**Polarization Measurement**

**Scheme 1.** Experimental schematics.

#### 2.2. Preparation of Methanol Extract and Separation of Alkaloids

All the chemicals used in this experiment were AR grade, collected from a local vendor, and used without purification. Liquor ammonia (25% w/w, sp.gr.0.905), methanol (99.85%, sp.gr.0.8957), tartaric acid (Lobachemie, 99%), and CHCl$_3$ (Fine chemicals, 99.5%, sp.gr. 1.491) were used. For the preparation of methanol extract, Rhizome of Rhynchostylis retusa (RR) was collected from the Godavari, Nepal (27.57° N, 85.37° E), washed and shade dried. The dried sample was ground into powder. 250 g of powder sample was soaked in methanol for 7 days followed by filtration to obtain extract as filtrate. This filtrate was taken as methanol extract. The pH of a dark brown extract was adjusted to alkaline by using tartaric acid and ammonia solution. Alkaloid was separated using CHCl$_3$ in the separating funnel. The dark green slurry of alkaloid extract was obtained in the organic layer. The organic layer thus obtained was separated, and concentrated using a rotary evaporator under reduced pressure and temperature. The concentrated extract was evaporated up to dry and labeled as alkaloids of RR.

#### 2.3. Test for Alkaloids

Extracted alkaloids were confirmed by qualitative chemical tests and spectroscopic test methods. In the qualitative chemical test, Mayer’s test and Dragendorff’s test methods were applied; for the spectroscopic method, the FTIR method was applied; for the chemical test, reagents of AR grade were applied. FTIR spectra of alkaloids were recorded in this work to find the functional group and N-C bond in the ring structure using an IR prestige
FTIR Spectrophotometer, Shimadzu, Japan. FTIR measurement of alkaloids has been carried out for predicting the active sites of molecules that are usually adsorbed on the metal surface.

2.4. Preparation of Acid and Inhibitor Solution

A stock solution of 1 M H$_2$SO$_4$ was prepared by taking 55.6 mL of concentrated H$_2$SO$_4$ (Fisher Scientific, Waltham, MA, USA, 98%, sp. gr. 1.84) in 1000 mL of the volumetric flask containing distilled water and diluted up to mark. This was taken as corrosive media. For the preparation of inhibitor medium, one gram of alkaloid of RR was dissolved in 1 M H$_2$SO$_4$ solution, and it was filtered to remove the un-dissolved extract. The filtrate was taken as 1000 ppm of stock solution. From 1000 ppm stock solution of the inhibitor, solutions of different concentrations were prepared by serial dilutions.

2.5. Weight Loss Measurement Method

The weight of each MS coupon before and after immersion in acid and inhibitor solution was measured using an analytical electronic balance (Ohaus Corporation, Parsippany, NJ, USA, Model: E1RR80). Measurements were carried out for each immersion experiment in inhibitor solution of different concentrations (200, 400, 600, 800, and 1000 ppm) as well as in different intervals of time (0.5, 3, 6, 9, and 24 h). Similarly, the temperature effect was studied by immersing the sample in 600 ppm inhibitor solution at 25, 35, 45, 55, and 65 °C for 6 h.

The corrosion rate (CR) and inhibition efficiency (IE%) were calculated using the formula:

\[
\text{Corrosion rate (CR)} = \frac{K \times W}{A \times T \times D} \quad (1)
\]

\[
\text{Inhibition efficiency (IE%)} = \frac{W_a - W_p}{W_a} \times 100 \quad (2)
\]

where, \(K = 87,600\), \(W = \) weight loss in gram, \(A = \) total surface area of coupons in cm$^2$, \(T = \) time of immersion in h, \(D = \) density of mild steel in g/cm$^3$, \(W_a = \) weight loss in the absence of inhibitors, \(W_p = \) weight loss in the presence of inhibitors.

2.6. Electrochemical Measurements

2.6.1. Open Circuit Potential

The open-circuit potential (OCP) is important to explain the mode of inhibition of alkaloid solution. For a better understanding of the corrosion behavior of MS, the measurement of OCP was conducted at laboratory temperature in both corrosive and inhibitor mediums. The measurement was carried out in the three-electrode system using a Hokuto Denko Potentiostat (HA-151, Hokuto Denko Corporation, Tokyo, Japan). The MS coupon, graphite rod, and saturated calomel electrode (SCE) were used as a working electrode, a counter electrode, and a reference electrode, respectively. The OCP was measured for 30 min as immersed and after 3 h immersion of the MS sample in the inhibitor solution of different concentrations.

2.6.2. Potentiodynamic Polarization

The polarization measurement method was used to evaluate the corrosion current, corrosion potential, and inhibition efficiency. The polarization was carried out in the arrangement as in the OCP measurement process. Before potentiodynamic polarization, a time interval of 30 min was given for each experiment to attain the steady-state OCP; then, the sample was subjected to cathodic and anodic polarization at a scan rate of 1 mV/s after 3 h immersion in acidic inhibitor solutions. The corrosion current densities were obtained by extrapolation of the linear Tafel segment of anodic and cathodic curves.
The corrosion inhibition efficiency and the fraction of surface area coverage (θ) were calculated using the following formulas:

\[
\text{Corrosion inhibition efficiency} = \frac{I_{\text{corr}} - I_{\text{corr}}^*}{I_{\text{corr}}} \times 100 \tag{3}
\]

\[
\text{Fraction of surface coverage (θ)} = \frac{I_{\text{corr}} - I_{\text{corr}}^*}{I_{\text{corr}}} \tag{4}
\]

where, \(I_{\text{corr}}\) and \(I_{\text{corr}}^*\) are corrosion current in the absence and presence of inhibitor respectively.

This research work was based on the following experimental schematics.

### 3. Results

#### 3.1. Test for Alkaloid

##### 3.1.1. Qualitative Chemical Test

Extracted alkaloids were confirmed by qualitative chemical tests and spectroscopic tests. A qualitative test for confirmation of the presence of alkaloids was performed by Mayer’s and Dragendroff’s test methods. The detailed observations are given in Table 1. The possible chemical reaction with the reagent used is given regarding the dendroxine molecule in Scheme 2 [24].

#### Table 1. Phytochemical screening of the extract solution.

| S.N. | Experiment       | Observation                                      | Inference     |
|------|------------------|--------------------------------------------------|---------------|
| 1    | Mayer’s Test     | The appearance of an orange precipitate.          | Alkaloid Presence |
| 2    | Dragendroff’s Test | The appearance of orange-red color.               | Alkaloid Presence |

#### Scheme 2. Possible chemical reactions involved in the chemical test of alkaloids.

##### 3.1.2. FTIR Spectroscopic Analysis

FTIR spectroscopic analysis was carried out to characterize alkaloids, Figure 2. The strong peak at 3000–2700 cm\(^{-1}\) is due to the N-H stretching vibration of primary and secondary ammonium ions, the peak at 2328 cm\(^{-1}\) is secondary amine multiple bonds, and the peak at 1514 cm\(^{-1}\) is due to N-H bending vibration. Peak around 1450 cm\(^{-1}\) is due to aromatic C-N stretching and multiple peaks at 1250–1020 cm\(^{-1}\) are due to C-N stretching of primary, secondary, and tertiary amines [25,26].
3.1.2. FTIR Spectroscopic Analysis

FTIR spectroscopic analysis was carried out to characterize alkaloids extracted from RR. In general, the FTIR spectra of alkaloids show various peaks due to the presence of different functional groups. The broad peak at 3000 cm\(^{-1}\)–3500 cm\(^{-1}\) is due to the N–H stretching vibration of primary and secondary amines, and C–H stretching vibrations. A strong peak at 1514 cm\(^{-1}\) is due to the C=N stretching of aromatic compounds. The peak at 1100 cm\(^{-1}\)–1300 cm\(^{-1}\) is due to secondary ammonium ions, the peak at 2328 cm\(^{-1}\) is due to N–H bending vibration. Peak around 1450 cm\(^{-1}\) is due to the N–H bending vibration of primary and secondary amines, and C–N stretching vibrations. The peak at 1650 cm\(^{-1}\) is due to aromatic C=N and C=C stretching vibrations. The peak at 2900 cm\(^{-1}\)–3000 cm\(^{-1}\) is due to C–H stretching vibrations of aliphatic carbon chains.

Figure 2. FTIR spectra of alkaloids extract of RR.

3.2. Effect of Immersion Time

Weight loss of MS and inhibition efficiency of alkaloids extracted from RR at various time intervals are observed and represented in Figure 3a,b, respectively. Initially, the weight loss in acid and the presence of the inhibitor is slightly different; however, later on, the weight loss of MS samples in presence of an inhibitor is significantly decreased. This shows that initially the protective layer of the inhibitor is not completely formed, but later the formation of the protective layer is completed, hence weight loss is minimized. Due to a longer period of exposure to MS in acidic medium desorption can also happen, which results in slight weight loss even in presence of an inhibitor.

Figure 3. (a) Variation of weight loss of MS samples in acid and in the presence of inhibitor solution at different intervals of time, and (b) Inhibition efficiency of alkaloid solution at different intervals of time.

The 1000 ppm inhibitor solution was used in this experiment. This concentration seems sufficient for the formation of a protective layer on the MS surface. Initially, there is very small weight loss; however, at a longer period of immersion time, the weight loss has increased. This may be due to the presence of defects on the inhibitor layer on the MS surface. This type of defect may arise due to orientation, size, and interaction among the inhibitor molecules. Even increasing in weight loss, the inhibition efficiency is constant; this is because the exposure of MS surface to the aggressive environment in the presence of inhibitor solution is only from the point of the defect however in absence of inhibitor all the
surface area is available for the aggressive environment, and this is much more pronounced than in the presence of an inhibitor.

3.3. Effect of Concentration

Immersion tests have been carried out in 200, 400, 600, 800, and 1000 ppm alkaloid solutions for 6 h to study the effect of inhibitor concentration. The observation showed that at low inhibitor concentration, high weight loss and low efficiency indicate a high corrosion rate. Here, the rate of corrosion decreases by increasing the alkaloid concentration. The maximum efficiency observed is 87.51% in 1000 ppm solution as in Figure 4a.

![Figure 4](image)

**Figure 4.** (a) Variation of weight loss of MS samples in acid and inhibitor solution at fixed intervals of time and (b) Inhibition efficiency of alkaloid solution at different intervals of time.

The surface morphology of the MS sample was studied by taking the optical image and microscopic image with a high-performance RXLr-4 microscope. Digital images of polished MS dipped in 1 M H₂SO₄ solution and the presence of a different concentration of inhibitor recorded are shown in Figure 5. The surface of the MS dipped in 1 M acid is very rough due to the formation of corrosion products but in the presence of an inhibitor, the surface of MS is being coated with inhibitor molecules. The green color of inhibitor molecules on the MS surface indicates the complete adsorption of inhibitor molecules. Due to the adsorption phenomenon, the surface of MS that dipped in the presence of inhibitor solution is smooth.

![Figure 5](image)

**Figure 5.** The digital images of MS surface (a,b) polished MS at different magnification, (c) after dipping in 1 M H₂SO₄ for 1 h, (d–h) after dipping in 200, 400, 600, 800, 1000 ppm green inhibitor respectively for 1 h at 25 °C.

An optical microscopic study was carried out in the presence of acid and green inhibitor solution layer on the MS. The optical images of MS surfaces that are dipped in
acid and the presence of green inhibitors in different magnifications are in Figures 6 and 7. The surface of MS dipped in the acid solution only at 0.5 h and 3 h immersion study reveals that there are large pits/grooves on the surface due to dissolution of MS surface by acid molecules. The formation of pits/grooves on the surface is higher in the 3 h immersion sample than in the 1 h immersed sample; however, inhibitor molecules are visible on the MS surfaces which are immersed in the presence of inhibitor. The surface of MS is very smooth for 1 h immersed sample than that of 3 h immersed sample; however, in both cases, inhibitors molecules are adsorbed on the surface, thus reducing the corrosion.

![Figure 6](image1.png)

**Figure 6.** The MS surface images (a–c) after 1 h dipping, and (d–f) after 3 h dipping in 1 M H$_2$SO$_4$ at different magnifications.

![Figure 7](image2.png)

**Figure 7.** The MS surface images (a–c) after 1 h dipping, and (d–f) after 3 h dipping at 25 °C in the solution of 1000 ppm green inhibitor at different magnifications.

3.4. Temperature Effect

The inhibition efficiency of the alkaloid inhibitor greatly depends on temperature. This effect was studied by taking reference to 600 ppm inhibitor solution at different temperatures. It is found that inhibition efficiency is almost constant at 25 °C and 35 °C but with the rise in temperature above it, the efficiency decreases, it may be due to desorption of inhibitor molecule from the metal surface, Figure 4b. This gives the key idea that there is physical adsorption between the inhibitor molecule and the MS surface.

3.5. Open Circuit Potential Measurements

OCP measurement of the MS in 1 M H$_2$SO$_4$ was studied by monitoring changes in OCP with time up to 30 min at laboratory temperature. The change in OCP of MS in acid and at
various concentrations of inhibitor solutions was recorded and analyzed. Measurement was carried out as immersed and after 3 h of immersion of MS in inhibitor solution as in Figure 8a,b, respectively.

![Figure 8.](image)

**Figure 8.** (a) Recorded OCP with a time of immersion of MS in different concentrations of inhibitor of 1 M H$_2$SO$_4$ in as-immersed condition, and (b) Recorded OCP with the time of immersion of MS in different concentrations of inhibitor of 1 M H$_2$SO$_4$, when measured after 3 h of immersion.

3.6. **Polarization Behaviour**

Potentiodynamic polarization measurement of MS sample was measured in three-electrode systems. It is observed that the corrosion current density decreased with the increase in the concentration of inhibitor solution, Figure 9. This may be due to the complete formation of inhibitor film on the MS surface as a result of increasing inhibitor concentration which results in a decrease in corrosion rate. It was further revealed that the efficiency was increased when the sample was immersed for 3 h than as immersed one. This is because it takes time to form an inhibition layer of inhibitor on the MS surface. After the formation of the layer, it prevents corrosion, decreases the current density, and hence increases inhibition efficiency.

![Figure 9.](image)

**Figure 9.** Potentiodynamic polarization curves for MS in 1 M H$_2$SO$_4$ containing different concentrations of inhibitor, when polarization is done immediately after 3 h of immersion.

The polarization curve also indicates that there is a decrease in current density with the addition of inhibitors. In the presence of an inhibitor, the MS surface is covered with inhibitor molecules so that the active site of MS is small. The reaction in this small area produces a small current density. This also indicates that the inhibitor used in this
The inhibition efficiency was calculated from the polarization method. The inhibition efficiency protects the MS from an aggressive environment and reduces the corrosion rate. The inhibition efficiency variation is shown in Figure 10. Based on the value of surface coverage and the inhibitor concentration used, various inhibition efficiencies were obtained from the polarization of 3 h immersed MS sample in 1 M H₂SO₄ in presence of inhibitor.

| Medium   | Ecorr (V) | Icorr (µA/cm²) | Surface Coverage (θ) | Inhibition Efficiency (%) |
|----------|-----------|----------------|-----------------------|---------------------------|
| Acid     | 0.429     | 340            | -                     | -                         |
| 200 ppm  | 0.432     | 182            | 0.4647                | 46.47                     |
| 400 ppm  | 0.449     | 107            | 0.6853                | 68.53                     |
| 600 ppm  | 0.452     | 71             | 0.7912                | 79.12                     |
| 800 ppm  | 0.451     | 45             | 0.8677                | 86.77                     |
| 1000 ppm | 0.454     | 23             | 0.9324                | 93.24                     |

The inhibition effect of used alkaloids is enhanced with increasing concentration. For 3 h immersed sample and all the concentrations of inhibitor, polarization was carried out. The inhibition efficiency was calculated from the polarization method. The inhibition efficiency of the 200 ppm inhibitor is very small whereas the inhibition by 400 ppm solution is in the acceptable range. From this drastic change in the inhibition efficiency, it can be generalized that more than 400 ppm inhibitor concentration may be the effective concentration. To attain steady-state equilibrium between adsorbed and free inhibitor molecules, the inhibitor concentration plays an important role. After 400 ppm, the inhibition gradually increases up to 1000 ppm concentration and inhibition reaches 93.24%. This is because, the higher the concentration of the inhibitor, the inhibitor molecule can have sufficient concentration to get adsorbed and attain an equilibrium state [26]. This adsorbed layer protects the MS from an aggressive environment and reduces the corrosion rate. The detail efficiency variation is shown in Figure 10.

**Figure 10.** Inhibition efficiency of inhibitor obtained from the polarization of 3 h immersed MS sample in 1 M H₂SO₄ in presence of inhibitor.

3.7. **Adsorption Isotherm**

Based on the value of surface coverage and the inhibitor concentration used, various adsorption isotherms have been tested. For reference, the molecular mass of the dendroxine molecule has been used; however, this only is not responsible for the inhibition. Langmuir isotherm has been tested by plotting C/θ versus C (mol/L) from Equation (5) and shown
in Figure 11a. The correlation coefficient ($R^2$) value is equal to 0.9994, indicating that the adsorption of inhibitor on the MS surface strongly obeys Langmuir adsorption isotherm and a monolayer of inhibitor formed on the MS surface before multilayer formation. From the value of intercept, the adsorption constant has been calculated and is used for the calculation of the free energy of the adsorption. The free energy of the adsorption has been found at 27.33 kJ/mol. This value is higher than the value of physical adsorption (<20 kJ/mol) and lower than chemical adsorption (>40 kJ/mol) indicating physical dominated chemical adsorption of inhibitor on MS surface [27,28]. This is also in accordance with OCP measurement indicating the mixed type inhibition by inhibitor.

\[
\frac{C}{\theta} = \frac{1}{K} + C
\]  

(5)

A plot of $\theta$ versus $\ln C$ from Equation (6) gives a straight line with a slope of 0.2881 and an $R^2$ value of 0.998 as in Figure 11b. The value of interaction parameter ‘a’ has been calculated from the intercept and found equal to negative 1.73 indicating the strong interaction between the adsorbed inhibitor molecules. The value of K has been calculated and found to be negative 2.09 indicating the inhibitor molecules are strongly adsorbed on the MS surface [28–30].

\[
\theta = -\frac{1}{2a} \ln C - \frac{1}{2a} \ln K
\]  

(6)

\[
\ln \theta = \ln K + \frac{1}{n} \ln C
\]  

(7)

Freundlich adsorption isotherm has been tested by plotting $\ln \theta$ versus $\ln C$ from Equation (7) as in Figure 11c. A straight line with $R^2$ value of 0.9807 and a slope $(1/n)$ value
equal to 0.4297 which is in the range $0 < 1/n < 1$ indicates the adsorption process is easy and spontaneous [28,29].

4. Discussion

Recorded data and calculated results of the weight loss measurement method indicate that initially inhibition efficiency (IE) is 48.07% which gradually increases up to 84.91% (at 6 h) and remains almost constant, Figure 3a. The formation of an inhibition layer on the MS surface may take a few minutes. At that duration, the mild steel sample was completely exposed to an acidic environment which leads the corrosion of that surface. The formation of a complete protective layer on the MS surface increases the inhibition efficiency. The efficiency of the inhibitor is not 100% which may be due to the dissolution of the protective layer or may be due to the presence of a vacant site between the large inhibitor molecules.

The effect of concentrations of inhibitor study reveals that, on increasing inhibitor concentration, weight loss gradually decreases and efficiency increases. This shows that IE is high as the concentration is increased. This change may be due to the increase in the covered fraction of the MS surface by the adsorbed molecules. Even if the experiment is performed at optimum inhibitor concentration, the efficiency of the inhibitor may not be 100% due to the desorption process. The temperature may be the next important factor for lowering efficiency. Effect of temperature for inhibition mechanism study reveals that at a higher temperature, the alkaloid molecules in the solution may lose their properties resulting in a decrease in inhibition efficiency. This implies that the adsorption of inhibitors on MS surface is physical adsorption. This claim has been confirmed by free energy calculation [31].

The OCP measurement in the presence of an inhibitor is shifted to a slightly negative direction (<50 mV) as compared to that of the acid solution, Figure 8a,b. This shows that alkaloid extract of RR acts as a mixed type of corrosion inhibitor. The shifting of OCP implies the formation of the protective film of inhibitor on the MS surface. There is a slight increase in potential in the middle, mainly in the 3 h immersed sample, which may be due to the destruction of the film formed at the metal surface due to corrosive attack. After a certain time, the value is constant indicating the reoccurrence of film at the metal surface.

The significant decrease in corrosion current with the addition of an inhibitor reveals that alkaloid acts as a good inhibitor. The polarization curve shows that only the cathodic curve is affected by the alkaloid extract of RR. Alkaloid acts as mixed type inhibitor as corrosion potential shift is less than 85 mV. Calculation shows that inhibition efficiency increases with an increase in the concentration of alkaloid in acid and it is up to 93.24% at 1000 ppm concentration in 3 h immersed sample.

The inhibition efficiency of the inhibitor calculated by polarization measurement is higher in comparison to the weight loss method. Lower the inhibition efficiency in weight loss measurement may be due to handling and systemic errors. The polarization measurement is almost error-free. Hence, the inhibition efficiency calculated by polarization measurement is more reliable.

5. Conclusions

Alkaloids have been extracted successfully from RR by the solvent extraction process. Qualitative chemical test (Dragendorff’s method) supports, and FTIR analysis shows the presence of N-H, O-H, N-O, -C=C- groups in the structure of alkaloid. It has been found that alkaloid inhibition increases with an increase in its concentration. Inhibitor protects mild steel from an aggressive environment by the formation of a protective layer on the surface through the adsorption process. Adsorption of the alkaloid (inhibitor) on the metal surface depends on the contact time, concentration and temperature. Due to this fact, inhibition efficiency is greatly influenced by temperature, concentration, and contact time. OCP measurement reveals that alkaloids extracted from RR inhibit by controlling both anodic and cathodic reactions, i.e., act as a mixed type of inhibitor. The inhibition efficiency of inhibitor by weight loss method is found to be 87.51% for 1000 ppm concentration.
Similarly, potentiodynamic polarization shows an inhibition efficiency of 93.24% of the immersed sample for 1000 ppm inhibitor concentration. The alkaloids perform well up to 35 °C.

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