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Case study

The dual effect of stem extract of Brahmi(Bacopamonnieri) and Henna as a green corrosion inhibitor for low carbon steel in 0.5 M NaOH solution

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ABSTRACT

The effect of stem Extract of Brahmi (Bacopamonnieri) and Henna on the rate of corrosion of low carbon steel were investigated in a solution of 0.5 M NaOH using the methods of weight loss measurements and potentiodynamic polarization. The findings revealed that the dual effect of stem extract had the role of being an effective inhibitor, the loss of weight experiments and the inhibition efficiencies gained from the polarization process were well matched. It was proved by conducting the potentiodynamic polarization method that the stem extract is an inhibitor of mixed type in an alkaline solution of 0.5 NaOH for low carbon steel through avoiding the reactions of both cathodic and anodic on a metal surface. Thus, the findings gained from the experiment of weight loss reveals the same effect of corrosion's inhibitions, the results show that when using different concentration of extract of Brahimi (Bacopamonnieri) and Henna solutions ranging between (0.5–2)% in 0.5 M NaOH at room temperature and 1 atm, the efficiency IEp % increased up to 80% which is resulting from polarization while the efficiency IE% increased up to 65% which is resulting from weight loss method.

1. Introduction

Carbon Corrosion is known as the electrochemical or chemical reaction that happens between a material and its environments which leads to a deterioration of that material and its characteristics. Corrosion happens when exposing a material to an unstable thermodynamically environment. Whereas, the degradation of material happens generally and not exclusively under the conditions of oxidizing [1].

Years ago, inhibitors in the industries were widely accepted due to their anti-corrosive traits. On the contrary, damaging the environment was shown as a side effect of these inhibitors. Therefore, the scholars started to search for inhibitors that are environmentally friendly such as the organic inhibitors [2].

Significant inhibition efficacy was shown by a synthetic inhibitor which is an inorganic inhibitor, in addition to some organic compound for inhibitor such as; oxygen, sulphur, and nitrogen. However, these elements are expensive and can cause danger to the environment leading to poisoning the living beings. Thus, more study is needed on natural inhibitors so it

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can be used without causing harm to the environment [3]. At room temperature the corrosion by NaOH is easily at all concentrations in a different of metals and alloys, such as carbon steels, so that in this work suggested that inhibition of low carbon steel in 0.5 M NaOH.

1.1. Aims and objectives

The research work aimed to study the behavior of green extract Henna as inhibitions of corrosion rates for low carbon steel in corrosive solutions of 0.5 M NaOH by using :

1 Polarization techniques to determine the corrosion rates at different solutions of green extract.
2 Weight loss measurement in the periodic duration at three months.

1.2. Literature review

A study was conducted by Wan Nik and colleagues in 2011showed that the extraction of Henna indicated to an inhibitor of mixed type, but mostly to the cathodic side. The extraction of Henna was found in the findings to work as an effective inhibitor for the type of type 5083 of aluminum alloy. Lawsone is found to be an essential component in henna that is responsible for the inhibition effect [3].

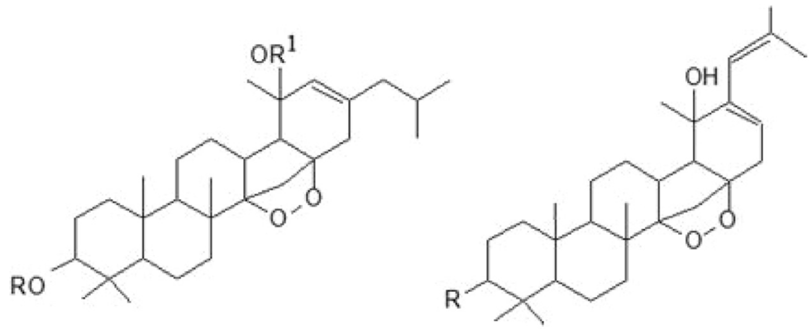
Singh and colleagues in 2012 [4] studied Bacopa monnieri as an aluminum corrosion inhibitor in a solution of 0.5 M NaOH through using the methods of potentiodynamic polarization, weight reduction estimations and electrochemical impedance spectroscopy (EIS).The findings showed that the extraction of the stem of Bacopa monnieri has a significant inhibiting effect, also the inhibition efficacies that are gained through the experiments of weight loss and polarization were well matched. It was proved by using the technique of potentiodynamic polarization that the extract is an inhibitor of mixed-type for aluminum when applying alkaline solution by avoiding both reactions of cathodic and anodic on a metal surface.

Johnsirani and colleagues in 2012 [5] investigated the inhibition efficiency (IE) of Henna leaves aqueous extraction at controlling carbon steel corrosion in sea water and it was evaluated through the method of weight-loss. The study of weight loss indicates that the compound consisting of 25 ppm of Zn^{2+} and 8 mL of henna extract (HE) has 94% IE at controlling carbon steel corrosion in seawater. Whereas, the study of Polarization shows that the system of Zn^{2+} and HE plays a role as an inhibitor of mixed type. The AC impedance spectra on the surface metal show the formation of a protective film. SEM, FTIR spectra and AFM analysis was used with the purpose of analyzing the nature of the metal surface.

A. H. Nour and Sh.El-Gendy 2013 [6], studied the carbon steel corrosion inhibition with the existence of a variety of concentrations of henna leaves aqueous extraction in a solution of 1 M HCl, and was examined by using the techniques of weight loss and potentiodynamic polarization. Moreover, temperature impact on the carbon steel's corrosion behavior was examined in a temperature of 293–333 K. The IE rises as increasing inhibitor concentration while drops down with elevating temperature. The physical adsorption mechanism is supported by free energies and activation for the inhibition. The henna extract adsorption on a surface of carbon steel is spontaneous, endothermic and compatible with the adsorption isotherm of Langmuir. The measurements of potentiodynamic polarization show that the extraction of henna plays as a mixed inhibitor. Surface analysis and the protective film was conducted by using; Fourier transforms infrared (FT-IR), spectroscopy, scanning electron microscopy (SEM), energy dispersive X-ray (EDX), and X-ray diffraction (XRD) analysis.

R. T. Vashi and N. I. Prajapati 2017 [7], investigated the inhibitive action of the leaves extraction of Bacopa monnieri (Brahmi) on the aluminum's corrosion in a solution of HCl by the methods of electrochemical impedance spectroscopic (EIS), otentiodynamic polarization and weight loss. The inhibitor concentrations effect on varied acid concentrations was studied. The current research showed that the percentage of IE is decreased when the temperature is increased while raised with the elevation of the concentration of the inhibitor. The extract inhibitive action is discussed from a point of view of Bacopa monnieri molecule adsorption on the metal surface. It was shown that the Langmuir adsorption isotherm happens first, then adsorption happens. Tafel plots of polarization study show that the leaves extract of Bacopa monnieri plays as a mixed type inhibitor. Maximum I.E. of Bacopa monnieri leaves extract was shown 91.85% at 1.2 g/L inhibitor concentration in 0.75 M HCl solution. Bacopa monnieri contains Brahmine, Monnierin, Saponins, Hersaponin, Bacoside -A, Bacoside –B and other chemicals such as; Stigmastanol, β -Sitosterol and Stigmasterol10,34-36.Bacopa monnieri contained alkaloid brahmine, nicotinine, and herpestine37, 38. Bacopa monnieri also contained betulinicacid, D-mannitol39.Bacoside- A[3-(α-L-arabinopyransoyl)-O-β-D-glucopyranoside-10, 20-dihydroxy-16-keto-dammer-24-ene] and Triterpenoid Saponins were isolated from Bacopa monnieri. The active constituents of Bacopa monnieri leave extract includes Bacoside-A and Bacoside-B whose structures are given below in Fig.1. [7].

Z. Khoshkhou, et al 2018 [8], assessed the impact of henna separate as an inhibitor consolidated into sol-gel network TMSM-PMMA, in HCL 0.1 M on carbon steel examples. The outcomes are as followings: 1) By utilizing henna separate, there was no hint of breaks and pits on the outside of the examples secured by a hybridorganic-inorganic slim film. 2) Hybrid covering TMSM-PMMA offers flimsy obstruction assurance and by the expansion of henna, the restraint proficiency arrives at higher than 95%. 3) SEM examinations for researching the morphology of the sol-gel coatings with henna concentrate have demonstrated that the consistency of covering has not diminished by including henna remove inhibitor. 4) Henna extricate



Bacoside-A Bacoside-B

Fig. 1. Structure of Bacoside- A and Bacoside- B.

as an inhibitor could be ordered as a blended sort kind which has an overwhelming effect in the cathodic piece of the polarization bend.

2. Methodology

The experimental works were divided into two parts. The first part has dealt with the study of low carbon steel corrosion behavior by using potentiostatic system for measurements of the corrosion rate by polarization of this alloy at different concentrations of green inhibitors in solution of 0.5 M sodium hydroxide, the second part of the experimental works, involves the study of the weight loss of the above mentioned. Carbon steel is the most used metal in various industries such in oil or gas transportation, pipelines, water cooling systems and storage tanks [9], related to its great mechanical properties [10]. The corrosion of carbon steel results in different type of corrosion for example pitting, rusting which are causing loss of materials and the mechanical/synthetic properties decay, carbon steel exposure to corrosion in all concentration of NaOH like in sea water, the corrosion inhibitors employed for protecting materials from unwanted corrosion [11].

2.1. Materials

1) Low carbon steel: the chemical compositions of standard low carbon steel ASTM A204grA/B/C steel by % Grades are: **C** 0.2 max, Mn 0.9 max, S 0.035 max, P 0.035 max and Si 0.15-0.4,while the chemical composition of carbon steel as measures by spectro, (Ametk, Materials spectrometer analyzer, Germany made) by % Grades are: **C** 0.226 max, Mn 0.44 max, S 0.0233 max, P 0.0081 max and Si 0.142
2) Sodium hydroxide: Sharman, molecular weight 40.

2.2. Apparatus and instrument

1 Polishing machine, Knuth-Rotor-3, Struers Co., Denmark.
2 A potentiostatic system, M Lab 200, Bank-Electronic, Germany.
3 Sensitive balance, TP-214, Denver instrument, max. 210 g.
4 Electronic precision balance; two decimal, (max. capacity 600 g).
5 Magnetic stirrer.
6 Centrifuge.

2.3. Preparation of solution

Corrosion solution electrolyte was obtained by mixing 20 g of NaOH with 1000 ml of distilled water with the purpose of preparing 0.5 M NaOH.

2.4. Stem extract preparation

Bacopa monnieri and Henna leaves were collected, dried and blended to powder form. 10 g powder of Bacopa monnieri and 5 g of Henna were refluxed in 250 ml double of distilled water in a period of 3 h. The refluxed solution was allowed with the purpose of standing for 30 min, filtered and stored. 0.5%, 1% and 2% of inhibitor concentration are prepared from a stock solution in 0.5 M of NaOH.

2.5. Electrochemical measurements

The method of potentiostatic polarization is broadly used with the purpose of determining the steady-state corrosion behavior of alloys and metals as a function of potential in the interest environments.

This method involves firstly holding a surface of the specimen at a constant potentials series against reference electrode, after that measured the current necessary with the purpose of maintaining all the applied potentials. According to that, there are numbers of parameters that are important for understanding the material's corrosion behavior in the environment.

Due to the existence of stem extract, an electrochemical technique was used to analyze the traits of the corrosion inhibition. Thus, an ordinary three electrode cylindrical glass cell was utilized with the purpose of conducting electrochemical measurements. In a disc from cut from the low carbon steel, the working electrode had a diameter of 15 mm and 2 mm thick. A saturated calomel electrode (SCE), a platinum electrode and auxiliary electrode were used as references respectively. The test was completed at room temperature, the potentiostatic system of the test is seen in Fig. 2.

2.6. Weight loss measurement

The carbon steel specimens were cut into cylindrical specimens with dimensions of 18.4mm⌀ × 17–19 cm thick sizeswith the purpose of using in the measurements of weight loss and the surface areas of specimens measured followingseries of using abrasive paper of silicon carbide (grade 600–1200) to abrade it and applying acetone to degreaser acetone, distilled water to rinse it and the air to dry it, then accurately weighed.

For three months, the carbon steel samples were immersed in 0.5 M NaOH with and without adding various stem extract levels. The corrosive system temperature was performed at room temperature. The carbon steel samples were thoroughly cleaned in distilled water after periods of immersion, dried out and weighed after that. The information on weight loss was gained through the median value of three parallel specimens of all various stem extract levels. The mass lost during the experiment was determined after that [12].

The average rate of corrosion can be achieved as following Eq. (1):

$$CR=(K \times W)/(A \times T \times D) \tag{1}$$

where:

CR: corrosion rate
K = a constant,
T = time of exposure in hours,
A = surface area in cm^2,
W = mass loss in milligrams, and D = density in g/cm^3.

Fig. 2. Potentiostatic system.

It is possible to use many varying units to show rates of corrosion. We are using millimeters per year (mm/y) as the units of corrosion rate so that the value of K is 87.6 [9].

3. Results of potentiostatic polarization measurements

The polarization process was carried out using the potentiostatic and with3-electrode electrochemical cell was utilized with Diskfix electrode as the working electrode with an exposing area of 1 cm^2 to the electrolyte, a Pt counter electrode and a calomel reference electrode was separated from the solution by a capillary Luggin probe, the reference electrode was moved very close to ~1-2 mm from the working electrodesurface to minimize the effect of the solution resistance. The electrochemical cell was assembled and the electrodes connected to the potentiostatic which was connected to a computer provided with the software (MlabSci version 4.1) to control and analyze the results of the electrochemical tests.

Firstly the open-circuit potential OCP or Ecorr was recorded during the 10 min of the test, and then the polarization was performed at a constant sweep rate of 1 mv/s and the scanning potential range was from +250 to -250 regarding the open circuit potential Ecorr. The polarization curves (E app. vs. Log I) was plotted and the extrapolation of Tafel region in the polarization curves was used to identify the corrosion current density Icorr and the corrosion potential Ecorr, which was used to identify the rate of corrosion using Faraday's law. Where the low carbon steel's corrosion behavior had been studied by measuring the corrosion currents densities (Icorr.) by Tafel slope extrapolation method in different concentrations of the extract of Brahimi (Bacopamonnieri) and Henna solutions in 0.5 M NaOH. Fig. 3. showed the polarization curves in the corrosive environments respectively. The electrochemical parameters, anodic Tafel slope (βa), cathodic Tafel slope (βc), corrosion potential (Ecorr.), and corrosion current density (Icorr.) for Low carbon steel corrosion in solutions are illustrated in Table 1., the corrosion current density was found to be elevated with increasing of extract of Brahimi (Bacopamonnieri) and Henna solutions. Concentration, and for corrosion current the maximum values in 0.5 M sodium hydroxide solution were observed at 0.5% and then decreased as increasing the concentrations of the solution to 2%.

From polarization measurements the inhibition efficiency (IE_P%) is determined by the following Eq. (2), [1], as the results which are shown in Table 2.

$$IE_P\% = \frac{Icorr - Icorr(i)}{Icorr(i)} \times 100 \quad (2)$$

Icorr and Icorr (i) indicate to the current density of corrosion in the absence and presence of inhibitors, respectively [1].

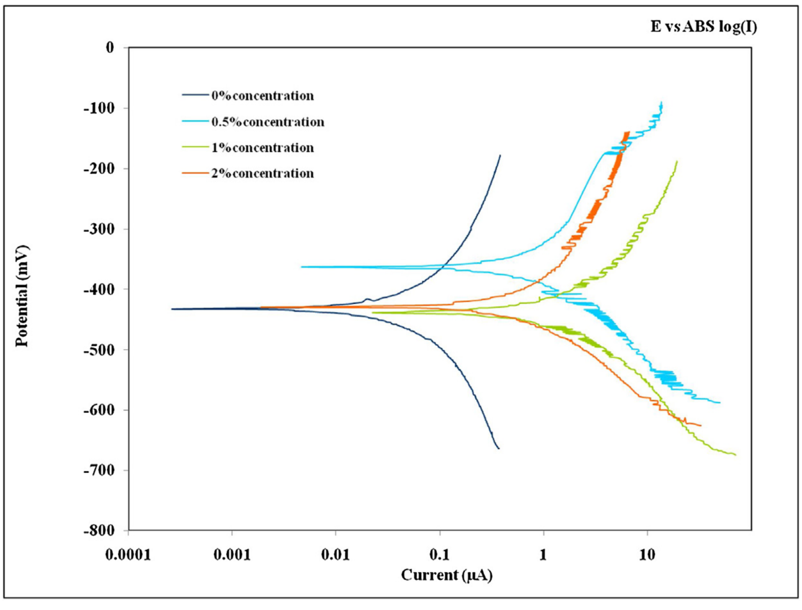


Fig. 3. Polarization curves of low carbon steel in 0.5 M NaOH and different concentration of extract of Brahimi (Bacopamonnieri) and Henna solutions at room temperature and 1 atm.

Table 1
Polarization parameters for the corrosion of low carbon steel in different concentration of extract of Brahimi (Bacopamonnieri) and Henna solutions in the 0.5 M NaOH.

Concentration%	Icorr. (mV)	Ecorr. nA	βc (mV/Dec)	βa (mV/Dec)
0	−432.6	18370.00	75.7	−78
0.5	−331.0	854.44	86.3	−155.3
1	−426.5	269.33	74.9	−68.4
2	−443.3	226.33	35.8	−16.1

Table 2
Inhibitor efficiency results from polarization measurements of low carbon steel in different concentration of extract of Brahimi (Bacopamonnieri) and Henna solutions at three months.

Concentration	IEp%
0	————
0.5	20.49946
1	67.20629
2	80.16467

4. Results of weight loss measurements

4.1. Estimation of surface area of the specimens

Using high precision vernier calipers, the length and diameters of carbon steel samples were determined and the calculation of the samples surface areas was carried out.

4.2. Weighing specimens

prior and post corrosion, all the weighing of the samples of carbon steel was performed with delicate equilibrium, TP-214, Denver instrument, max. 210 g.

4.3. Estimation of corrosion rate

The weighed samples were immersed in 100 mL beakers containing 100 mL of different test solutions, the samples were taken out following twenty-four hours of immersion, using running water to wash it, then dried and weighed. Corrosion rates were calculated from the change in weights of the samples using the relationship in Eq. (2). Then the equation below was used to compute corrosion inhibition efficiency (IE%):

$$IE\% = 100 \times \left[1 - \left(\frac{CR_2}{CR_1}\right)\right] \tag{3}$$

Where CR_1 corrosion in the absence of an inhibitor and CR_2 corrosion in the presence of an inhibitor.

The results of inhibitor efficiency by using weight loss measurements are shown in Table 3.

The results of Tables 2 and 3 are shown in Fig. 4, it is clear that efficiency increase as the concentrations increase, significantly the efficiency IEp % between 20–80% which is resulting from polarization while the efficiency IE% between 15–65% which is resulting from weight loss method.

Table 3
Corrosion rate and inhibitor efficiency results from weight loss measurements of low carbon steel in different concentration of extract of Brahimi (Bacopamonnieri) and Henna solutions at three months.

Concentration	CR (mm/y)	IE%
0	0.019511	————
0.5	0.016429	15.79897
1	0.0103997	46.69957
2	0.006801	65.14523

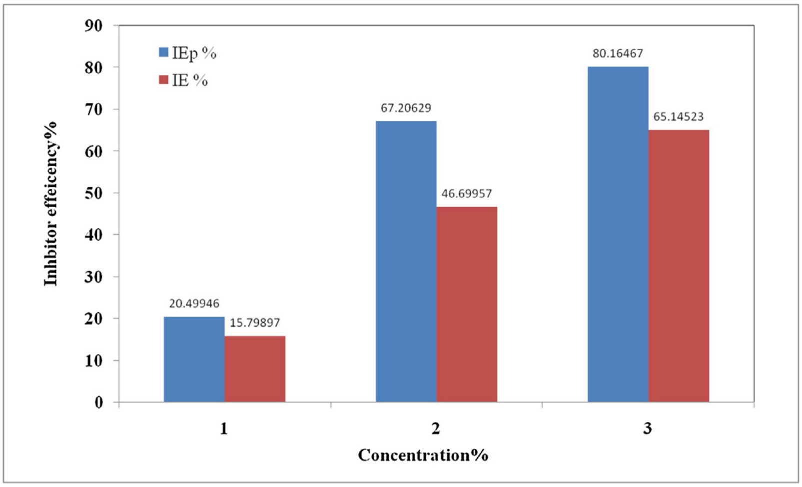


Fig. 4. The efficiency of different concentration of extract of Brahimi (Bacopamonnieri) and Henna solutions in 0.5 M NaOH for low carbon steel.

5. Conclusion

1) Extract of Bitter leaf (Vernonia amygdalina) reduces the amount of low carbon steel corrosion in 0.5 M NaOH solution from 0.5% to 20% inhibitor during120 days.
2) Physical adsorption is the process of interaction between the inhibitor and the alloy. The adsorbed molecules of the inhibitor are connected to the alloy surface by blocking active corrosion sites, therefore, the corrosion rate is lowered.
3) At 0.5% concentration in 0.5 M NaOH,the inhibitor exhibits little signification to prevent corrosion.

6. Recommendations

1) The inhibitor must be used for a short periodic time only in order to avoid the biological effect, so that recommended to study the changing in properties of inhibitor at long periods of time.
2) Study the impact of temperature and pH of solutions on the behavior of low carbon steel such as mechanical properties.
3) Also,it was suggested as characterization techniques, X-ray diffraction and microstructure study to demonstrate the characteristics of the studied low carbon steel.

Author Contribution

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

Declaration of Competing Interest

None.

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