Original Research Article

**Experimental evaluation of inhibition capabilities of** **expired Promethazine-Theoclate as corrosion control of mild-steel in Hydrochloric acid**

**ABSTRACT**

|  |
| --- |
| It was proposed to study the corrosion of mild-steel in hydrochloric acid solution with expired promethazine-theoclate as an inhibitor. This drug was characterized for its functional groups and chemical constituents using the Fourier Transform Infra-red and gas chromatography spectrophotometers. Experimental techniques and gravimetric methods were also employed. The inhibitory effects of the drug were assessed. Studies and regression analysis based on artificial neural network, and response surface methodology models complement the experimental findings. The predominant functional groups were; O-H, CO-NH-CO stretching; =C-H stretching; and N-H deformation. The drug consists of Phenol, 2,4- di-tert-butylphenol, 1-Heptadecene, tridecane, and propyl 11-octadecenoate. The heat of adsorption results was negative, indicating the flow of heat from the inhibitor-mild steel interface at a seemingly higher temperature to the surroundings at a lower temperature. The adsorption of the inhibitor molecules was physical and not chemisorption. The Frumkin isotherm provided the best fit and optimum efficiency of 93.71% was attained. ANN yielded better optimization results with higher value of R2 and lower values of RMSE and SEP. The impedance method displayed a capacitive loop, signifying charge-transfer process, and polarization measurements showed that the drug was a mixed-type inhibitor. Available studies have not investigated inhibitory actions of expired promethazine-theoclate in acidic environments, hence, the drug proved to be an excellent inhibitor for controlling mild steel corrosion in acidic media. Therefore, this study aims to fill this gap by evaluating the inhibition capabilities of the drug to provide new insights into corrosion science and pharmaceutical applications. |

***Keywords:*** *Evaluation, corrosion, inhibition, drug, control, mild-steel, Hydrochloric-acid.*

**1. INTRODUCTION**

Steel is a versatile engineering material that is widely used in various applications owing to its excellent ductility, toughness, high machinability, and weldability **[**Morcillo, M., De La Fuente, D., Diaz, L., Cano, Y. H. (2011), Noor, E. A., and Al Moubaraki, A. H. (2008)**]**. A large portion of the steel produced is utilized in chemical industrial sectors to handle salt, acid, and alkali solutions **[**Shetty, D.S., Shetty, P., and Nayak, H.V.S. (2006)**]**. Although mild-steel has added to the challenge of dealing with corrosion, its continued use and popularity as an engineering material is not only based on its good mechanical properties but also on good economic advantages owing to its relative accessibility and affordability **[**Chigondo, M., & Chigondo, F. (2016)**]**. Thus, preserving the functionality of these metallic structures and increasing their service life depend heavily on the corrosion protection of the metallic substrates. Acid solutions used in industries cause severe corrosion of metallic structures.

Inhibitors are substances added to corrosive environments to alter the reaction between the environment and metal surface, thereby preventing or reducing corrosion. Corrosion inhibitors control or prevent corrosion via various mechanisms **[**Rani, B. E., & Basu, B. B. J. (2012)**,** Omotioma, M. & Onukwuli O. D. (2016a)**]**.

Corrosion is simply the degradation of a substance caused by an inevitable reaction with the environment. According to **[**Speller, F. N. (1951)**]**, this may also refer to the degradation of materials due to the chemical activity of their surroundings. A metal that interacts with its surroundings and sustains damage due to accidental chemical or electrochemical attacks is said to have undergone corrosion. According to **[**Revie, R. W., & Uhlig, H. H. (2008)**]**, it causes metal loss through the breakdown and loss of properties, which puts equipment safety at risk.

Because corrosion requires the maintenance and replacement of metallic structures that break prematurely, it is a significant economic loss. According to **[**Iannuzzi, M., & Frankel, G. S. (2022)**]**, global corrosion damage was over 2.5 trillion dollars, or 3-4% of global GDP. More focus is placed on prevention and control as a more workable and realistic approach to minimizing the impact of corrosion damage because there are numerous factors that contribute to corrosion. These include the nature of metals, their variability in the environment, and their applications. This ensures that corrosion is inevitable, making it difficult to eliminate **[**Rani, B. E., & Basu, B. B. J. (2012)**]**. The use of inhibitors is the most practical and dependable method to prevent corrosion under acidic and aqueous conditions **[**Solomon, M. M., & Umoren, S. A. (2015), Omotioma M., Onukwuli O.D., & Obiora-Okafo I. (2019)**]**. There has been a significant rise in the use of pharmaceutical drugs as corrosion inhibitors **[**Pathak, R. K., & Mishra, P. (2016)**]**. Because most drugs are synthetic forms of organic chemicals, they are environmentally benign. In acidic solutions, several medications, including irbesartan, cephapirin, ampicillin, chloramphenicol, tramadol, and sodium diclofenac salt, have been utilized as corrosion inhibitors. Consequently, expired medications should be used to profit from drug waste. The approach addresses both economic and environmental issues **[**Fouda, A.S., Mahmoud, W. M., & Abdul Mageed, H. A. (2016)**]**. Therefore, the wide application of hydrochloric acid, potassium hydroxide etc., and metals such as carbon steel and aluminum have given the need for the present study to ‘investigate the actions of expired promethazine-theoclate in hydrochloric acid as corrosion resistance of mild-steel’. However, the inability of the mild steel to form a passive layer renders it vulnerable to corrosive attacks.

According to the iron-carbon phase diagram, all binary alloys with less than 2.11 weight percent carbon are categorized as steels, and alloys with more carbon are referred to as cast iron **[**Smil, V. (2016)**].** Iron is abundant in the Earth's crust and has the following features: high fusion temperature (1534°C), a variety of mechanical properties such as moderate yield strength (200–300 MPa) with excellent ductility to exceed the yield stress, tensile strength that can exceed 1400 MPa, and fracture toughness up to 100 MPa/M1/2.

Various criteria are used to categorize steels, including the form of component (plate, bar, strip, sheet, etc.), the deoxidation process for killed, semi-killed, and rimmed steel, and the microstructure of ferritic, austenitic, and matensitic steels. Additional factors include the heat treatment, manufacturing process, strength requirements, and finishing form **[**Singh, R. (2012)**]**. Because chemical composition of steel has the greatest impact on all other criteria and influences how other variables affect its influence, it is the most widely used method for categorizing steel. Steel can be divided into two main groups based on its chemical makeup: alloy and carbon steel **[**Smil, V. (2016)**]**.

Steels with alloying elements purposefully added to obtain the desired qualities are known as alloy steels. Different strengthening methods, work together to give alloy steels their overall strengths **[**Morales, E. V. (2011)**]**. Alloy steels are divided into two categories: low alloy-steels and stainless steel. Low-alloy steels have much better mechanical attributes such as strength and hardenability, but they are not as useful in extreme environments such as high temperatures and caustics. Stainless steel is advised under these extreme circumstances. According to **[**Pramanik, A., & Basak, A. K. (Eds.). (2015)**]**, stainless steel is an alloy steel that contains more than ten weight percent chromium and other alloying elements. These alloy steels are resistant to corrosion under a variety of chemical conditions because they contain more than 10% chromium, which forms passive oxide coating on alloy surfaces.

Matensitic, ferritic, and austenitic stainless steels are the three main varieties of stainless steels. The primary subtype of stainless steels, known as austenitic stainless steels, frequently has high concentrations of Nikel. Currently, applications requiring high corrosion resistance and exceptional mechanical qualities are dominated by austenitic stainless steels **[**Morales, E. V. (2011)**]**.

Plain carbon steel; is an alloy with 2% carbon by weight. Although residual components such as silicon, manganese, and aluminum can be detected in trace amounts, no alloying element has been purposefully introduced to change or improve the properties **[**Bhadeshia, H., & Honeycombe, R. (2017)**]**. When strength and other property requirements are not critical, and when high temperatures and corrosive conditions do not play a significant role in the material selection process, plain carbon steel is suitable **[**Singh, A., Gupta, A., Rawat, A.K., Ansari, K. R., Quraishi, M. A. & Ebenso, E.E. (2014)**]**. Because of this, it constitutes the majority of steel used in engineering and other applications. The greatest impact on mechanical qualities is shown by variations in carbon content, where, a higher carbon content results in a higher hardness and strength. Therefore, carbon steels are typically grouped based on the amount of carbon they contain.

Because of its many uses, low-carbon steel, sometimes referred to as mild-steel, has carbon a content of 0.0005 to 0.25 weight percent. It is also known as a general-purpose steel **[**Islam, T., & Rashed, H. M. (2019)**]**. Among several types of steel, those produced in the greatest quantities fall into the low-carbon category. Because they cannot be strengthened by heat treatment through the creation of matensite, cold work can be used. Despite its relative softness, some of its desired qualities, such as toughness, malleability, and extraordinary ductility, are mostly due to the prevalence of ferrite and pearlite in its microstructure **[**Kakani, S. L., and Kakani, A. (2004)**].** Mild-steel is the preferred material for most applications owing to its excellent machinability, weldability, and comparatively low manufacturing cost. Common uses include auto body parts, which can make up 50% to 60% of weight of vehicles. Additional applications include: off-highway vehicles, ships, structures, bridges, and pressure vessels. Pipeline designers almost exclusively choose structural steels for their demanding applications, which include pipelines, gas platforms, and offshore oil installations. This is valid for pipeline systems that are used to carry materials over lengths of hundreds of feet or kilometers, such as those used to collect water, natural gas, or crude oil.

Considering the vulnerability of mild steel to corrosion, which inevitably causes significant economic losses, its availability and relatively low cost have ensured that it will continue to be in demand in engineering and industrial applications. Over time, it has been demonstrated that the most effective method to prevent corrosion of mild steel and aluminum is the use of corrosion inhibitors. However, the use of organic and inorganic chemical corrosion inhibitors is restricted owing to high cost of their synthesis, reduced biodegradability, toxicity, and environmental hazards.

Therefore, it is necessary to identify appropriate substitutes for pharmaceutical drugs that have expired. Utilizing expired medications could solve two additional delicate issues: lowering drug-related environmental pollution and reducing drug disposal expenses. The majority of expired medications contain amines, and some also have functional groups in their molecular structures such as sulfide, sulfoxide, or sulfonamide. Promethazine-Theoclate was utilized in this study to regulate mild-steel corrosion in hydrochloric acidic HCl solution under various operating conditions.

Available studies have not investigated the actions of expired promethazine-theoclate drugsin acidic environments. Previous studies have explored various drugs such as pyrazinamide, isoniazid, rifampicin, atenolol, sulfamethoxazole and norfloxacin for use as mild-steel corrosion inhibitors, but the efficacy of expired promethazine-theoclate drugremains unexplored. This study aims to fill this gap by conducting experiments to evaluate the corrosion inhibition capabilities of this substance. This study aimed to provide new insights into corrosion science and pharmaceutical applications through systematic experiments and analyses.

**2. MATERIAL AND METHODS**

**2.1 Material**

## 2.1.1 Equipment

Mild-steel used was composed of S (0.12%), Cr (0.02%), C (0.24%), Mn (0.13%), Ni (0.07), P (0.22%), Si (0.05%), and Fe (99.15%). HCl was used as the acid solution in this study. Other material include: expired drug (promethazine-theoclate), distilled water, filter paper, thread, masking tape, emery papers, volumetric flasks, beakers, conical flasks, measuring cylinder, funnel stop-watch, thermometer, retort stand, electronic weighing balance water bath, petri-dish, oven, knife, and grinding machine. The major equipment used for instrumental analyses was the impedance electrochemical system EIS, and scanning electron microscopy SEM (-RhenomProx).

**2.1.2 Preparation of HCl Solution**

1 M HCl solution was prepared analytically using distilled water. Analytical grade acid was used. Distilled water (700ml) and 54.35 ml of HCl were mixed in one-liter measuring cylinder and more distilled water was added to make up the solution to one liter.

**2.1.3 Preparation of Concentrated Promethazine Theoclate**

Different concentrations of expired drug were prepared. In each liter flask, 10g of the drug was added to make a solution of sulphuric acid, H2SO4. Of these, solutions of inhibitor were prepared at concentrations of 0.2g/L - 1.0 g/L from the stock solution.

## 2.1.4 Mild Steel Preparation

The 3 x 3 cm mild-steel specimens were cut into coupons. To obtain a shiny, polished surface, coupons were degreased with acetone, cleaned with distilled water, dried naturally, and placed in desiccators to eliminate any remaining oil and organic contaminants. The initial weight of each coupon was recorded with accuracy and labeled for easy identification during the corrosion control study.

**2.2 Methods**

**2.2.1 Characterization of expired drug, Promethazine -Theoclate**

Chemical analysis of the drug was performed. The combined features of mass spectrometry (MS) and gas chromatography (GC) were applied to identify various substances within the drug sample. When heated, the drug breaks down into separate substances. The heated materials were passed through a nitrogen-filled column to identify compounds.

**2.2.2 Functional groups of the drug**

High spectral resolution data over a broad range were simultaneously collected using spectrophotometer. The raw data were transformed into an actual spectrum using Fourier transform infrared FTIR. Analyses of the different FTIR-produced peaks were conducted to identify the proper functional groups **[Furniss, B. S., Hannaford, A. J., Smith, P. W. G., & Tatchell, A. R. (1989),** Onukwuli, O.D & Omotioma, M. (2016)**].** Metals were submerged in the medium while the inhibitor was present to obtain the corrosion products. In conclusion, corrosion products were gathered in beakers.

**2.2.3 Weight Loss Method**

*2.2.3.1 Weight loss based on OFAT*

The OFAT based method was applied, (varying each of the factors: temperature, time, and inhibitor concentrations, while the remaining two factors were kept constant). Using this method, 200 ml of 1 M HCl (blank) was placed in separate 250 ml open beaker containing weighed metal coupons. Additionally, different inhibitor concentrations were added to a 250ml open beaker containing 200ml of 1 M HCl. This process was performed for each metal coupon.

From time to time, variations in weight loss were observed at different concentrations of acid solution, at different temperatures between 303K and 343K; with and without different inhibitor concentrations of 0.2g/L to 1.0g/L. The coupons were removed, submerged in acetone, cleaned, and weighed again at regular intervals.

Experimental readings were recorded. Weight loss (∆w), corrosion rate (CR), inhibition efficiency (IE) and degree of surface coverage *Ɵ* were determined with equations (2.1), (2.2), (2.3) and (2.4) respectively **[**Onukwuli, O.D & Omotioma, M. (2016)**,** Umoren, S. A., Eduok, U. M., Solomon, M. M., & Udoh, A. P. (2016)**,** Omotioma, M., & Onukwuli O. D. (2017)**,** Fouda, A. S., Ahmed, A. M., El-Darier, S. M., & Ibrahim, I. M. (2021)**]:**

 (1)

 (2)

 (3)

 (4)

Weight loss values in the presence and absence of the inhibitor are symbolized by *w*1 and *w*0, respectively, while wi and wf signify the initial and final weights of mild-steel. A, symbolizes mild-steel total area, ‘t’ was immersion time and *Ɵ* surface coverage.

**2.2.4 Thermodynamic properties**

**a**) Heat of adsorption was calculated with Equation (2.5).

(5)



where R is the gas constant, and *θ1* and *θ2* were degrees of surface coverage at temperatures T1 and T2 respectively.

**b**) Fitting experimental data to adsorption isotherms

The degree of surface coverage data was utilized for the application of various adsorption isotherms, including Flory-Huggins, Langmuir, Frumkin, and Temkin.

1. The Langmuir isotherm is expressed in Equation (2.6) **[**Onukwuli, O. D., & Omotioma, M. (2019)**,** Udeh B. C., Onukwuli O. D., & Omotioma M. (2021)**,** Umoren, S. A., Eduok, U. M., Solomon, M. M., & Udoh, A. P. (2016)**,** Fouda, A. S., Ahmed, A. M., El-Darier, S. M., & Ibrahim, I. M. (2021)**].**

(6)



C was concentration; K equilibrium constant and *θ* coverage or in log form,

Log () = log(c) – log(k) (7)

2. The Frumkin isotherm is given by Equation (2.8) **[**Omotioma, M., Green, T. B., Okorie, O., Ekete, J. A., & Aliozo O. S. (2024a)**].**

(8)



where α was lateral interaction term.

3. The Temkin isotherm is expressed by Equation (2.9) **[**Onukwuli, O. D., & Omotioma, M. (2019)**].**

*𝜃*= - 2.303logk/2**a** -0.303logc/2**a** (9)

where **a,** was attractive parameter.

4. The Flory-Huggins’ isotherm is expressed by Equation (2.10) **[**Onukwuli, O. O., Udeh, B. C., Omotioma, M., & Nnanwube, I. A. (2021)**].**

(10)



where **x** was size parameter.

The Gibbs free energy of adsorption (∆Gads) was calculated using Equation (2.11) **[**Onukwuli, O.D & Omotioma, M. (2016)**].**

(11)



where R is the gas constant, and T is the temperature. The K values obtained from the isotherms (Langmuir, Frumkin, Temkin and Flory-Huggins’ isotherms) were used to obtain the values of ∆Gads.

**2.2.5 Weight loss method using response surface methodology, RSM**

This was used in the experimental design of the weight-loss strategy. Temperature, time, and inhibitor concentration were the variables considered; The study's response was the efficiency of the expired drug. Tables 1, and 2 display the factors and the experimental design matrix. In accordance with earlier reports **[**Omotioma, M., & Onukwuli, O. D. (2016b)**,** Anadebe, V. C., Onukwuli, O. D., Omotioma, M. & Okafor, N. A. (2019**],** response of each case was analyzed using RSM, to further reveal the fitness of the model. Predictions regarding the responses for specific levels of each factor were made using models in terms of coded factors. High levels were coded +1 and low levels -1.

**Table I. Factors**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Factor** | **Name** | **Units** | **Type** | **Min.** | **Max.** | **Coded low** | **Coded high** | **Mean** | **Std. Dev.** |
| A | Inhibitor conc. | g/mL | Numeric | 0.6000 | 1.0000 | -1 ↔ 0.60 | +1 ↔ 1.00 | 0.8000 | 0.1451 |
| B | Temperature | K | Numeric | 303.00 | 323.00 | -1 ↔ 303.00 | +1 ↔ 323.00 | 313.00 | 7.25 |
| C | Time | hr | Numeric | 1.0000 | 5.00 | -1 ↔ 1.00 | +1 ↔ 5.00 | 3.00 | 1.45 |

**Table 2. Experimental Design Matrix**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Std** | **Runs** | **Factor A**  **g/L** | **Factor B**  **K** | **Factor C**  **hr** | **Response (efficiency)**  **%** |
| 4 | 1 | 1 | 323 | 1 |  |
| 3 | 2 | 0.6 | 323 | 1 |  |
| 13 | 3 | 0.8 | 313 | 1 |  |
| 15 | 4 | 0.8 | 313 | 3 |  |
| 20 | 5 | 0.8 | 313 | 3 |  |
| 12 | 6 | 0.8 | 323 | 3 |  |
| 1 | 7 | 0.6 | 303 | 1 |  |
| 8 | 8 | 1 | 323 | 5 |  |
| 5 | 9 | 0.6 | 303 | 5 |  |
| 16 | 10 | 0.8 | 313 | 3 |  |
| 18 | 11 | 0.8 | 313 | 3 |  |
| 9 | 12 | 0.6 | 313 | 3 |  |
| 14 | 13 | 0.8 | 313 | 5 |  |
| 6 | 14 | 1 | 303 | 5 |  |
| 19 | 15 | 0.8 | 313 | 3 |  |
| 2 | 16 | 1 | 303 | 1 |  |
| 17 | 17 | 0.8 | 313 | 3 |  |
| 11 | 18 | 0.8 | 303 | 3 |  |
| 10 | 19 | 1 | 313 | 3 |  |
| 7 | 20 | 0.6 | 323 | 5 |  |

**2.2.6 Prediction of inhibition efficiency using artificial neural network (ANN)**

An input-output data problem was fitted using an ANN. It involved the selection of data with neural network fitting tool, which is followed by the creation of a network **[**Pilkington, J., Preston, C., Gomes, R. L. (2014)**,** Nnanwube I. A., & Onukwuli D. O. (2020)**].** As part of the process, the network was trained and its performance was evaluated. The data were categorized into three categories: training, validation, and testing. The network was adjusted and validated to halt training when generalization stopped improving **[**Pilkington, J., Preston, C., Gomes, R. L. (2014)**].** It stopped when there was an increase in mean square error of the validation samples. The mean-square-error (MSE) was measured as the average squared difference between the predicted outputs and actual targets. Lower values of MSE were better, as a zero value indicates no error. The statistical criterion was regression R-values, which measured the correlation between the outputs and targets.

ANN optimization involving regression analyses, performance evaluations, and training analyses, was carried out using statistical tools, as shown in Equations (12), (13), and (14), respectively **[**Nnanwube I. A., & Onukwuli D. O. (2020)**,** Omotioma, M., Green, T. B., Okorie, O., Ekete, J. A., & Aliozo O. S. (2024a)**].**

(12)

(13)

(14)

where n was number of sample points, Ypred, predicted efficiency, 𝑌exp, determined efficiency, and Yexp. ave, experimental average.

**2.2.7 Mild-steel surface study using scanning electron microscopy (SEM)**

Mild-steel samples were studied using the SEM.

**2.2.8 Electrochemical Techniques**

The effectiveness and type of expired drugs were determined using electrochemical techniques. Three electrodes were used in the study. The reference, counter, and working electrodes were mild-steel specimens fixed in epoxy resin and exposed to the test solution. Electrochemical measurements were performed in accordance with the methods used in **[**Omotioma, M., Onukwuli, O. D., & Nnanwube, I. A. (2024c)**,** Anadebe, V. C., Onukwuli, O. D., Omotioma, M. & Okafor, N. A. (2018**].**

**3.0 RESULTS AND DISCUSSION**

**3.1 Characteristics of expired drug: Promethazine -Theoclate**

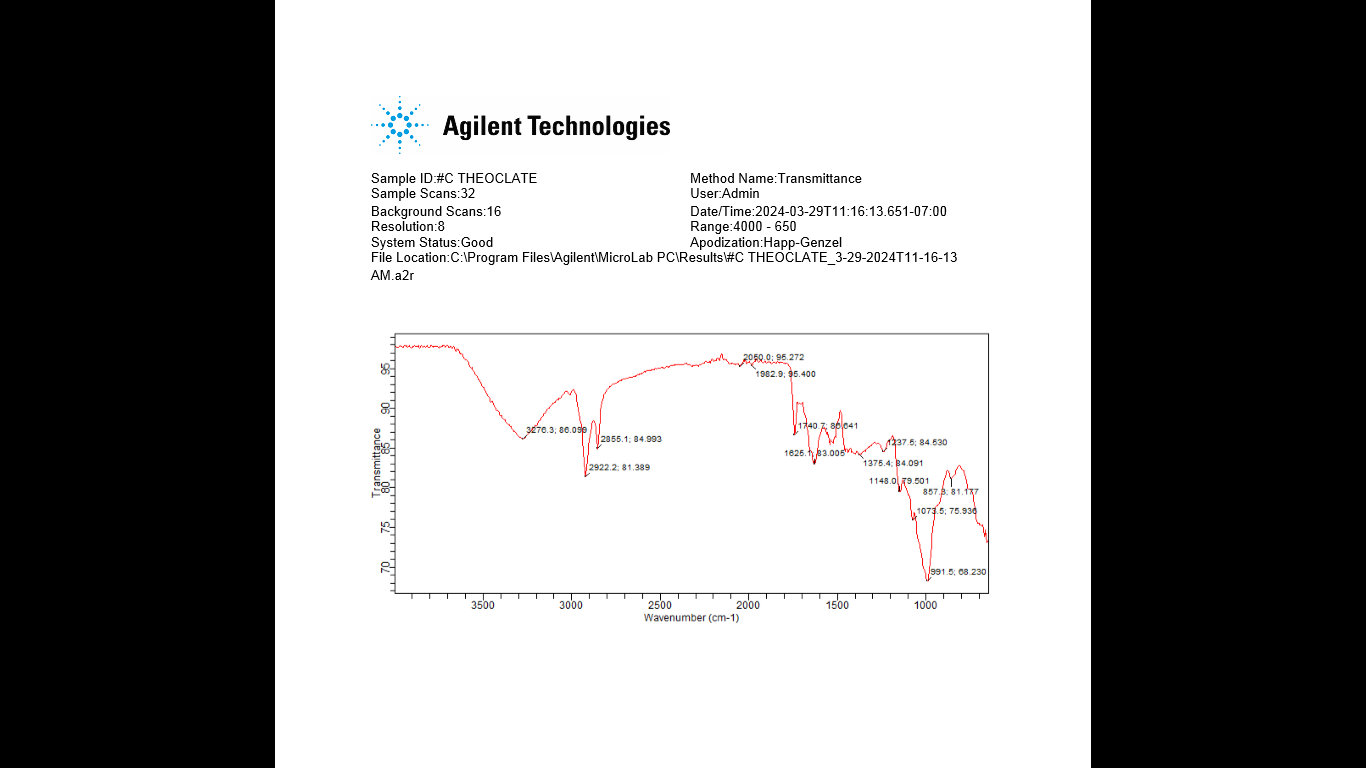
**3.1.1 Functional groups.**

The FTIR spectra of the drugs are shown in figure 1. Each spectrum shows the relationship between the transmittance and wave number representing the functional groups.

The identified functional groups are also presented in Table 3 and include: O-H stretch, CO-NH-CO, C-H stretch, N-H deformation, C-O-C stretch, =C-H stretching and C-F stretching. The drug contained nitrogen and oxygen heteroatoms.

This table lists the peaks observed in the spectroscopic analysis of promethazine-theoclate, their intensities, and the corresponding functional groups and classes of compounds.

The above details help to analyze the chemical structure and functional groups present in the compounds.



**Fig. 1. Spectrum of Promethazine -Theoclate**

**Table 3. Functional groups of the Promethazine -Theoclate**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| S/N | Peaks | Intensity | Functional Group | Class of Compounds |
|  | 3276.3 | 86.099 | O-H Strech | Carboxylic |
|  | 2922.2 | 81.389 | C-H | Alkene and Alkyls |
|  | 2855.1 | 84.993 | C-H | Alkene and Alkyls |
|  | 1982.9 | 95.400 | C-H | Alkene and Alkyls |
|  | 1740.7 | 86.641 | CO-NH-Co | Carbonyl Group |
|  | 1625.1 | 83.005 | N-H Deformation | Carbonyl Group |
|  | 1375.4 | 84.091 | C-O Stretching | Alcohols and Phenols |
|  | 1237.5 | 84.530 | O-H Deformation | Alcohols and Phenols |
|  | 1148.0 | 79.501 | C-O-C Stretch | Ethers |
|  | 1073.5 | 75.936 | C-F Strech | Alkyl halides |
|  | 991.5 | 68.230 | =C-H Stretching | Alkenes |
|  | 857.8 | 81.177 | =CH2 deformation | Alkene and Alkyls |

**3.1.2 Chemical constituents of the drug**

The chemical constituents of the drugs are listed in Table 4. Promethazine-Theoclate contains phenol, 2,4-di-tert-butylphenol, tridecane, cyclo-hexadecane, n-propyl 11-octadecenoate and 1-Heptadecene. The presence of these substances shows that promethazine-theoclate has the capacity to antagonize a variety of receptors, allowing it to be used for a number of indications including corrosion inhibition, as expressed by **[**Omotioma, M., Okolo N. W., Okorie, O., Ekete, J. A., & Aliozo O. S. (2024b)**].**

**Table 4. Chemical constituents of Promethazine -Theoclate**

|  |  |
| --- | --- |
| **Peaks** | **Chemical Constituents** |
| 1-4 | De-cane, Etha-none, 3-Trifluoroacetoxytetradecane |
| 5-8 | phenol, 2,4-di-tert-butylphenol, tridecane, |
| 9-12 | Diethyl Phthalate, Dodecanoic acid, Tetra-decanoic acid, Nonadecane, n-Hexa-decanoic acid |
| 13-16 | Heneicosane, Linoelaidic acid, 9-Octadecenoic acid, Cyclo-hexadecane |
| 17-20  21-24  25-28 | 3-Eicosene, 1-Docosene, 3-Eicosene, Cyclo-tetracosane, cis-Vaccenic acid  Oleic acid, Erucic acid, n-Propyl 11-octadecenoate, Behenyl chloride  cis-Vaccenic acid, 1-Heptadecene, 1-Hexacosene, 1-Octadecene |

**3.2 Effects of Independent Factors**

The effects of the process inhibitor of mild-steel in HCl solution are presented in Table 5. The weight loss and corrosion rate decreased with increasing inhibitor concentration. The efficiency also increased with concentration. peak inhibition efficiency of 92.89% (promethazine-theoclate) was reached at 0.8g/L inhibitor concentration because of increase in electrostatic attraction between molecules. Beyond the maximum point, the inhibition efficiency showed slight decrease. The observed retardation may be due to the force of attraction between the molecules of the inhibitor and surface of mild-steel **[**Ezeugo, J. N. O., Onukwuli, O. D., & Omotioma, M. (2017)**,** Omotioma, M., & Onukwuli O. D. (2017)**,** Paul, P. K., Yadav, M., & Obot I. B. (2020)**,** Qurishi, M. A., Chauhan, D. S., & Saji, V. S. (2021)**].** Weight loss and corrosion rate increased with temperature. Consequently, an increase in temperature decreases the efficiency levels of promethazine-theoclate as an inhibitor may be due to the force of mild-steel **[**Verma, C., Quarishi M. A., Ebenso, E. E., Obot, I. B., El Assyry, A. (2016)**,** Paul, P. K., Yadav, M., & Obot I. B. (2020)**,** Deyab, M. A. (2020)**].**

The inhibition efficiency increased with time. It collaborates with the reports of previous research works **[**Singh, A., Gupta, A., Rawat, A.K., Ansari, K. R., Quraishi, M. A. & Ebenso, E.E. (2014)**,** Popova, A., Christov, M., & Vasilev, A. (2015)**,** Udeh B. C., Onukwuli O. D., & Omotioma M. (2021)**],** which stated that the efficiency of the inhibitor improves with time. The high inhibition efficiency may be due to viable hetero-atom.

**Table 5. Effects of the Independent Factors**

**Effect of time**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Time (hr) | ∆W0 (g) | CR0 (mg/cm2hr) | ∆W1 (g) | CR1 (mg/cm2hr) | IE (%) | Ɵ |
| 1 | 0.157 | 17.44 | 0.028 | 3.111 | 82.17 | 0.8217 |
| 2 | 0.308 | 17.11 | 0.037 | 2.056 | 87.99 | 0.8799 |
| 3 | 0.506 | 18.74 | 0.036 | 1.333 | 92.89 | 0.9289 |
| 4 | 0.511 | 14.19 | 0.045 | 1.250 | 91.19 | 0.9119 |
| 5 | 0.527 | 11.71 | 0.051 | 1.133 | 90.32 | 0.9032 |
| **Effect of concentration**  0.0 | 0.506 | 18.74 |  |  |  |  |
| 0.2 |  |  | 0.175 | 6.481 | 65.42 | 0.6542 |
| 0.4 |  |  | 0.144 | 5.333 | 71.54 | 0.7154 |
| 0.6 |  |  | 0.103 | 3.815 | 79.64 | 0.7964 |
| 0.8 |  |  | 0.036 | 1.333 | 92.89 | 0.9289 |
| 1.0 |  |  | 0.048 | 1.778 | 90.51 | 0.9051 |
| **Effect of temperature** |  |  |  |  |  |  |
| 303 | 0.422 | 15.63 | 0.041 | 1.519 | 90.28 | 0.9028 |
| 313 | 0.506 | 18.74 | 0.036 | 1.333 | 92.89 | 0.9289 |
| 323 | 0.557 | 20.63 | 0.081 | 3.000 | 85.46 | 0.8546 |
| 333 | 0.722 | 26.74 | 0.147 | 5.444 | 79.64 | 0.7964 |
| 343 | 0.81 | 30 | 0.195 | 7.222 | 75.93 | 0.7593 |

**3.3.1 Heat of adsorption**

The heat of adsorption (Qads) for corrosion control is presented in Table 6. Qads had negative values for all concentrations ranging from 0.2g/L to 1.0g/L. This means that adsorption was accompanied by the release of heat. This was similar to the reports of **[**Verma, C., Quarishi M. A., Ebenso, E. E., Obot, I. B., El Assyry, A. (2016)and Omotioma, M., Okolo N. W., Okorie, O., Ekete, J. A., & Aliozo O. S. (2024b)**]**, where a negative value for the heat of adsorption was an indication of an exothermic process. The status of Qads showed flow of heat from the inhibitor mild-steel interface at a seemingly higher temperature to the surroundings at a lower temperature.

**Table 6. Heat of adsorption for corrosion control in HCl using Promethazine -Theoclate**

|  |  |
| --- | --- |
| **Conc. (g/L)** | **Heat of ads, Qads (J/mol) Promethazine theoclate** |
|  |
| 0.2 | -56322.4 |
| 0.4 | -57796.6 |
| 0.6 | -73081 |
| 0.8 | -67151.6 |
| 1.0 | -53399.4 |

**3.3.2 Adsorption Results**

The results of these parameters are listed in Table 7. The Frumkin isotherm was the best-fitted isotherm. This assertion was based on the recorded highest average value of the coefficient of determination (R2); where the average value was closest to the critical value of 1 (one) compared to the R2 values of the other isotherms (Frumkin, Temkin and Flory-Huggins). In the Temkin results, the attractive parameter (a) values were negative implying no chemical reaction between mild steel and promethazine-theoclate. The lateral interaction term (α) at 313K and 323K was positive. This means that was a noticeable attraction between promethazine-theoclate and mild-the steel surface. Positive values of size property (x), were revealed by analysis of the Flory-Huggins’ isotherm, indicating reasonable layer of drug attachment to the mild-steel. Gibb’s free energy was lower than -40.00kJ/mol, hence adsorption was physical **[**Onukwuli, O.D & Omotioma, M. (2016)and Azeez, F. A., Al-Rashed, O. A, Nazeer., A. A. (2018)**].**

**Table 7. Results of parameters**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Isotherms** | **Temperature (K)** |  | **K** | **∆Gads**  **(J/mol)** | **Isotherm property** | |
| Langmuir  Isotherm | 313 | 0.9926 | 0.9192 | -10218.7 |  | |
| 323 | 0.9555 | 0.8297 | -1`0219.3 |
| Temkin  isotherm | 313 | 0.898 | 178.074 | -10312.2 | a | -2.8320 |
| 323 | 0.8282 | 33.481 | -10545.2 | -2.1273 |
| Frumkin  Isotherm | 313 | 0.9942 | 0.02221 | -10234.3 | α | 2.62365 |
| 323 | 0.9768 | 0.0889 | -10286.1 | 1.8540 |
| Flory-Huggins  Isotherm | 313 | 0.7028 | 4.4300 | -10234.3 | x | 0.5998 |
| 323 | 0.5383 | 2.4121 | -10332.5 | 0.5245 |

**3.3.3 Optimization Results**

The RSM results and optimization data are listed in Table 8. maximum value of efficiency was 92.55% at 0.8g/L, 313K and 3hrs. This indicates that effects of the variables are parabolic and conform with the quadratic model **[**Onukwuli, O.D & Omotioma, M. (2016)and Azeez, F. A., Al-Rashed, O. A, Nazeer., A. A. (2018)**].**

**Table 8. RSM results**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Std** | **Run** | **Factor A**  **g/L** | **Factor B**  **K** | **Factor C**  **hr** | **Response (efficiency)**  **%** |
| 4 | 1 | 1 | 323 | 1 | 60.76 |
| 3 | 2 | 0.6 | 323 | 1 | 46.67 |
| 13 | 3 | 0.8 | 313 | 1 | 84.03 |
| 15 | 4 | 0.8 | 313 | 3 | 92.55 |
| 20 | 5 | 0.8 | 313 | 3 | 92.55 |
| 12 | 6 | 0.8 | 323 | 3 | 77.59 |
| 1 | 7 | 0.6 | 303 | 1 | 59.86 |
| 8 | 8 | 1 | 323 | 5 | 75.69 |
| 5 | 9 | 0.6 | 303 | 5 | 62.78 |
| 16 | 10 | 0.8 | 313 | 3 | 92.55 |
| 18 | 11 | 0.8 | 313 | 3 | 92.55 |
| 9 | 12 | 0.6 | 313 | 3 | 77.58 |
| 14 | 13 | 0.8 | 313 | 5 | 90.54 |
| 6 | 14 | 1 | 303 | 5 | 77.75 |
| 19 | 15 | 0.8 | 313 | 3 | 92.55 |
| 2 | 16 | 1 | 303 | 1 | 68.86 |
| 17 | 17 | 0.8 | 313 | 3 | 92.55 |
| 11 | 18 | 0.8 | 303 | 3 | 86.38 |
| 10 | 19 | 1 | 313 | 3 | 86.93 |
| 7 | 20 | 0.6 | 323 | 5 | 52.71 |

**3.3.4 Quadratic models’ ANOVA**

The ANOVA of the quadratic models’ ANOVA were shown in Table 9 for the promethazine-theoclate efficiency in HCl solution.

**Table 9. Quadratic models’ ANOVA for the Promethazine -Theoclate efficiency in HCl solution**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Source** | **Sum of Sq** | **Df** | **Mean Sq** | **F-value** | **P-value** | |  |
| Model | 4160.60 | 9 | 462.29 | 220.43 | < .0001 | | Sigt |
| A | 495.48 | 1 | 495.48 | 236.26 | < .0001 | |  |
| B | 178.17 | 1 | 178.17 | 84.96 | < .0001 | |  |
| C | 154.37 | 1 | 154.37 | 73.61 | < .0001 | |  |
| AB | 21.45 | 1 | 21.45 | 10.23 | .0095 | |  |
| AC | 27.60 | 1 | 27.60 | 13.16 | .0046 | |  |
| BC | 10.49 | 1 | 10.49 | 5.00 | .0493 | |  |
| A² | 363.14 | 1 | 363.14 | 173.16 | < .0001 | |  |
| B² | 380.41 | 1 | 380.41 | 181.39 | < .0001 | |  |
| C² | 114.81 | 1 | 114.81 | 54.75 | < .0001 | |  |
| Residual | 20.97 | 10 | 2.10 |  |  | |  |
| Lack of Fit | 20.97 | 5 | 4.19 |  |  | |  |
| Pure Error | 0.0000 | 5 | 0.0000 |  |  | |  |
| Cor Total | 4181.57 | 19 |  |  |  | |  |
| Std. Dev. | 1.45 |  | R² | | | .9950 | |
| Mean | 78.17 |  | Adj R² | | | .9905 | |
| C.V. % | 1.85 |  | Pred R² | | | .9611 | |
|  |  |  | Adeq Prec | | | 44.7538 | |

***3.3.4 Quadratic model of inhibition efficiency of* Promethazine -Theoclate**

The generated models were quadratic. The coded equation was useful in identifying the relative impact of the factors by comparing the coefficients. The equation in terms of actual factors can be used to predict responses for each factor, but the levels should be specified in the original units. The equation in terms of actual factors should not be used to determine the relative impact of each factor because the coefficients were scaled to accommodate the units of each factor and the intercept was not at the center of the design space.

**3.3.5 Diagnostic report**

Equation in terms of coded factors for promethazine-theoclate in HCl

Inhibitor efficiency = +93.03+7.04A-4.22B+3.93C+1.64AB+1.86AC+1.15BC-11.49A²-11.76B²-6.46C²

(**15**)

Equation in terms of the actual factors for promethazine theoclate in HCl

Inhibitor efficiency = -11259.87613 + 224.64955Inhibitor concentration + 72.37729Temperature - 9.97770Time + 0.818750Inhibitor concentration x Temperature + 4.64375Inhibitor concentration x Time + 0.057250Temperature x Time - 287.28409Inhibitor concentration² - 0.117614Temperature² - 1.61534Time² (**16**)

Table 10 presents report of the diagnostic analysis for corrosion control using promethazine-theoclate. Predicted, residual, leverage, difference in fit (DFFIT) and Cook’s distance were determined. A graphical analysis of the predicted versus actual inhibition efficiencies of the drug were presented in figure 2. These are linear graphs, where points are huddled along the line of the best fit. This figure also shows the generated data.

**Table 10. Report for the Promethazine -Theoclate efficiency in HCl**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Run Order** | **Actual Value** | **Predicted Value** | **Residual** | **Leverage** | **Internally Studentized Residuals** | **Externally Studentized Residuals** | **Cook's Distance** | **Influence on Fitted Value DFFITS** | **Standard Order** |
| 1 | 60.76 | 60.84 | -0.0785 | 0.793 | -0.119 | -0.113 | 0.005 | -0.221 | 4 |
| 2 | 46.67 | 47.20 | -0.5305 | 0.793 | -0.805 | -0.790 | 0.249 | -1.547 | 3 |
| 3 | 84.03 | 82.64 | 1.39 | 0.491 | 1.347 | 1.412 | 0.175 | 1.387 | 13 |
| 4 | 92.55 | 93.03 | -0.4785 | 0.118 | -0.352 | -0.336 | 0.002 | -0.123 | 15 |
| 5 | 92.55 | 93.03 | -0.4785 | 0.118 | -0.352 | -0.336 | 0.002 | -0.123 | 20 |
| 6 | 77.59 | 77.05 | 0.5438 | 0.491 | 0.526 | 0.506 | 0.027 | 0.497 | 12 |
| 7 | 59.86 | 61.21 | -1.35 | 0.793 | -2.046 | -2.546 | 1.605 | -4.985 | 1 |
| 8 | 75.69 | 74.70 | 0.9885 | 0.793 | 1.501 | 1.618 | 0.864 | 3.168 | 8 |
| 9 | 62.78 | 63.06 | -0.2805 | 0.793 | -0.426 | -0.408 | 0.070 | -0.798 | 5 |
| 10 | 92.55 | 93.03 | -0.4785 | 0.118 | -0.352 | -0.336 | 0.002 | -0.123 | 16 |
| 11 | 92.55 | 93.03 | -0.4785 | 0.118 | -0.352 | -0.336 | 0.002 | -0.123 | 18 |
| 12 | 77.58 | 74.50 | 3.08 | 0.491 | 2.983 | 8.515 | 0.858 | 8.362 | 9 |
| 13 | 90.54 | 90.50 | 0.0438 | 0.491 | 0.042 | 0.040 | 0.000 | 0.040 | 14 |
| 14 | 77.75 | 77.58 | 0.1715 | 0.793 | 0.260 | 0.248 | 0.026 | 0.486 | 6 |
| 15 | 92.55 | 93.03 | -0.4785 | 0.118 | -0.352 | -0.336 | 0.002 | -0.123 | 19 |
| 16 | 68.86 | 68.30 | 0.5645 | 0.793 | 0.857 | 0.845 | 0.282 | 1.655 | 2 |
| 17 | 92.55 | 93.03 | -0.4785 | 0.118 | -0.352 | -0.336 | 0.002 | -0.123 | 17 |
| 18 | 86.38 | 85.49 | 0.8918 | 0.491 | 0.863 | 0.851 | 0.072 | 0.836 | 11 |
| 19 | 86.93 | 88.58 | -1.65 | 0.491 | -1.593 | -1.750 | 0.245 | -1.718 | 10 |
| 20 | 52.71 | 53.63 | -0.9235 | 0.793 | -1.402 | -1.484 | 0.754 | -2.906 | 7 |



**Fig. 2. Predicted against actual efficiency of Promethazine -Theoclate in HCl**

***3.3.6 Three dimensional 3-D plots of* Promethazine -Theoclate**

3-D plots of RSM analysis of the efficiencies of the inhibitors are presented in figure 3. The interactive effects of the independent factors on the dependent variable displayed parabolic curves in all cases. The nature of the graphs (parabolic curves) supports the earlier explanation that the quadratic model fits the factors. In addition, 3-D plots showcased optimum parameters as determined by the optimization tool.

(a) (b)



(c)

**Fig. 3. Efficiency of Promethazine -Theoclate versus (a) temperature and concentration in HCl, (b) time and concentration in HCl and (c) time and temperature in HCl.**

**3.3.7 Optimum results of RSM**

The optimum values of the corrosion control parameters are presented in Table 11. In HCl solution, promethazine-theoclate had higher efficiency of 93.27%. This may be due to the higher quality of the phytochemicals and the intensity of the functional groups. The recorded high efficiencies show that promethazine-theoclate is suitable for controlling mild-steel corrosion in acid solutions.

**Table 11. Optimum results of the corrosion inhibition process**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Media** | **Opt. conc. (g/L)** | **Opt. temp. (k)** | **Opt. time (hrs)** | **Opt. IE (%)** |
| Mild steel in H2SO4 with Promethazine -Theoclate | 0.85 | 316.16 | 3.46 | 92.39 |

**3.3.8 Validation of results**

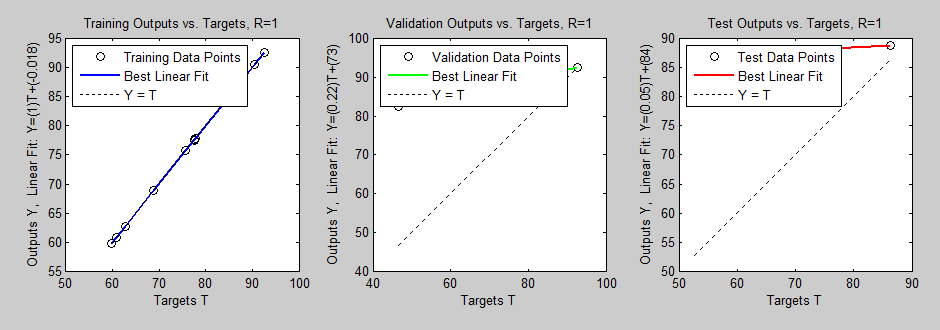
Table 12 presents the validation of the RSM results. At optimum conditions, the predicted and experimental values of the inhibition efficiency were compared using the percentage deviation as a statistical tool. recorded values were less than 5% hence the model effectively predicted the experimental data.

**Table 12. Validation of results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Media** | **Opt. conc. (g/L)** | **Opt. temp. (k)** | **Opt. time (hrs)** | **Opt. IE (%)** | **Exp. IE (%)** | **Percentage deviation (%)** |
| Mild steel in HClwith promethazine theoclate | 0.85 | 316.16 | 3.46 | 92.39 | 92.23 | 0.17 |

**3.3.9 ANN results**

The ANN results for corrosion control are presented using the regression evaluation graphs in figure 4. Validation and testing were performed on the graphical results. Points of the training data were clustered on the line of the best fit. Statistical analysis of the performance in terms of the mean square error and correlation of determination are equally presented.



**Fig. 4. ANN regression for prediction of efficiency of Promethazine -Theoclate for corrosion control of mild-steel in HCl**

**3.3.10 RSM and ANN Results of Corrosion Control.**

The RSM and ANN results of corrosion control using promethazine-theoclate are presented in Table 13. The experimental, RSM predicted and ANN predicted efficiencies are reported as functions of time, temperature and concentration.

**Table 13 RSM and ANN results of Promethazine -Theoclate efficiency in HCl.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Std** | **Runs** | **F A**  **g/L** | **F B**  **K** | **F C**  **hr** | **Actu IE**  **(%)** | **RSM pred IE (%)** | **ANN pred IE (%)** |
| 4 | 1 | 1 | 323 | 1 | 60.76 | 60.84 | 60.74 |
| 3 | 2 | 0.6 | 323 | 1 | 46.67 | 47.2 | 46.65 |
| 13 | 3 | 0.8 | 313 | 1 | 84.03 | 82.64 | 84.01 |
| 15 | 4 | 0.8 | 313 | 3 | 92.55 | 93.03 | 92.53 |
| 20 | 5 | 0.8 | 313 | 3 | 92.55 | 93.03 | 92.53 |
| 12 | 6 | 0.8 | 323 | 3 | 77.59 | 77.05 | 77.57 |
| 1 | 7 | 0.6 | 303 | 1 | 59.86 | 61.21 | 59.84 |
| 8 | 8 | 1 | 323 | 5 | 75.69 | 74.7 | 75.67 |
| 5 | 9 | 0.6 | 303 | 5 | 62.78 | 63.06 | 62.76 |
| 16 | 10 | 0.8 | 313 | 3 | 92.55 | 93.03 | 92.53 |
| 18 | 11 | 0.8 | 313 | 3 | 92.55 | 93.03 | 92.53 |
| 9 | 12 | 0.6 | 313 | 3 | 77.58 | 74.5 | 77.56 |
| 14 | 13 | 0.8 | 313 | 5 | 90.54 | 90.5 | 90.52 |
| 6 | 14 | 1 | 303 | 5 | 77.75 | 77.58 | 77.73 |
| 19 | 15 | 0.8 | 313 | 3 | 92.55 | 93.03 | 92.53 |
| 2 | 16 | 1 | 303 | 1 | 68.86 | 68.3 | 68.84 |
| 17 | 17 | 0.8 | 313 | 3 | 92.55 | 93.03 | 92.53 |
| 11 | 18 | 0.8 | 303 | 3 | 86.38 | 85.49 | 86.36 |
| 10 | 19 | 1 | 313 | 3 | 86.93 | 88.58 | 86.91 |
| 7 | 20 | 0.6 | 323 | 5 | 52.71 | 53.63 | 52.69 |

**3.2.11 Comparison of ANN and RSM results.**

The comparative results of the ANN and RSM in terms of RMSE, SEP, and R2 are presented in Table 14. ANN had a smaller root-mean-square-error (RMSE) and standard error of prediction (SEP). This observation showed a better prediction than RSM, which is in line with previous studies **[**Pilkington, J., Preston, C., Gomes, R. L. (2014)**,** Nnanwube I. A., & Onukwuli D. O. (2020)and Omotioma, M., Onukwuli, O. D., & Nnanwube, I. A. (2024c)**],** where the superiority of ANN over RSM was mentioned. Basis on the correlation of determination (R2), the ANN also had a higher value. Thus, ANN performed better than RSM in predicting the efficiency of promethazine-theoclate inhibitor.

**Table 14. Comparison of the predictions of ANN and RSM in terms of RMSE, SEP and R2.**

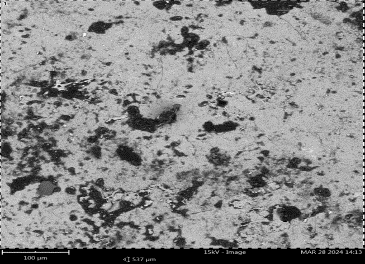
|  |  |
| --- | --- |
| **Comparison of Prediction** | **RMSE SEP R2** |
| RSM | 1.023863 1.309765 0.985884 |
| ANN | 0.018 0.023026 0.999996 |

**3.3.12 SEM-EDX results**

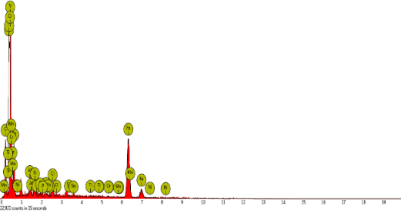
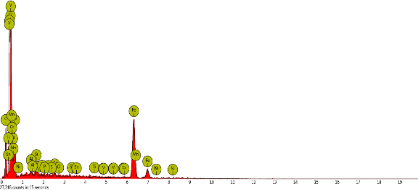
The SEM-EDX results are presented in figures 5a and 5b, where the surface morphologies of mild-steel, were subjected to corrosion in uninhibited and inhibited HCl solution. The mild-steel in figure 5a in the uninhibited solution was deeply corroded compared with the inhibited solutions in figure 5b, which had a lesser corrosion impact. Observations are in line with the findings of **[**Onukwuli, O.D & Omotioma, M. (2016)**],** which stated that metal was more seriously damaged in an uninhibited medium than in an inhibited medium. The results show changes in the elemental compositions of mild-steel surface. The effective corrosion control of mild-steel in acid solutions using promethazine-theoclate was established by revealing of the morphological results.

The mild-steel in figure 5a has the following elements with their numbers, symbols, atomic concentrations and weight concentrations in the order of: Fe 26, 24.06, and 55.29; Carbon C 6, 69.35, and 34.28; Silicon Si 14, 1.50, and 1.73; Chlorine Cl 17, 1.41, and 2.06; Aluminum Al 13, 2.02, and 2.25; Tin Sn 50, 0.21, and 1.02; Manganese Mn 0.10, 0.23, and 0.66; Sulfur S 16, 0.30, and 0.33; Titanium Ti 22, 0.15, and 0.25; Phosphorus P 15, 0.35, and 0.45; Vanadium V 23, 0.21 and 0.41; Nickel Ni 28, 0.00, and 0.00; and Chromium Cr 24, 0.13, and 0.29.

Similarly, in figure 5b, mild-steel has the following elements: Fe 26, 28.11, and 61.54; Carbon C 6, 66.92, and 31.51; Silicon Si 14, 1.73, and 1.91; Aluminum Al 13, 2.02, and 2.25; Tin Sn 50, 0.15, and 0.71; Chlorine Cl 17, 0.54, and 0.75; Sulfur S 16, 0.29, and 0.36; Phosphorus P 15, 0.29, and 0.33; Nickel Ni 28, 0.00, and 0.00; Chromium Cr 24, 0.16, and 0.33; Vanadium V 23, 0.06, and 0.12; Titanium Ti 22, 0.27, and 0.51; and Manganese Mn 25, 0.29, and 0.35.



|  |  |
| --- | --- |
|  |  |
|  |  |

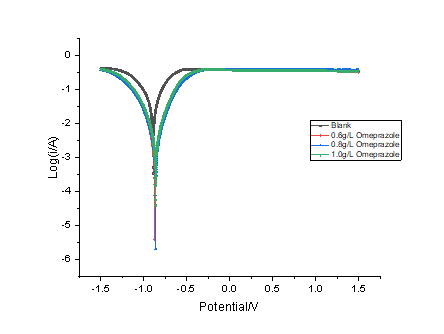
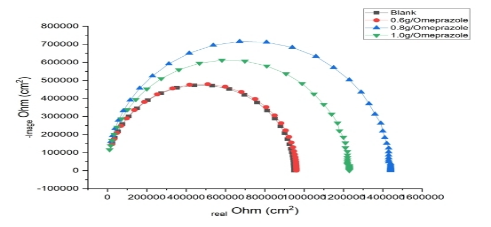
 

1. (b)

**Fig. 5. SEM-EDX result of mild-steel in (a)an uninhibited HCl and (b) HClwith Promethazine -Theoclate.**

**3.3.13 Electrochemical Results**

The electrochemical results presented in figures 6a and 6b, are for impedance spectroscopy and potentio-dynamic polarization, respectively. Higher inhibitor concentrations produced larger capacitive loops in inhibited solution indicating that the mild-steel had a higher corrosion resistance in presence of the inhibitor. Impedance spectroscopic technique (EIS) exhibits capacitive loop indicating a charge-transfer process-controlled corrosion reaction **[**Karthik, G., & Sundaravadivelu, M. (2016)and Vengatesh, G., Karthik, G., & Sundaravadivelu, M. (2017)**].** Increased inhibitor concentration inhibited anodic and cathodic reactions as observed from polarization curves, indicating that promethazine-theoclate was a mixed-type inhibitor.

1. (b)

**Fig. 6. Electrochemical Results (a) PDP result and (b) EIS result of Promethazine -Theoclate in HCl.**

**4. CONCLUSION**

* The predominant functional groups of the drug were the O-H stretch, CO-NH-CO, C-H stretch, N-H deformation, C-O-C stretch, =C-H stretching and C-F stretching. It contained nitrogen and oxygen hetero-atoms.
* Promethazine -Theoclate in HClmedium can be used to inhibit corrosion of mild-steel
* The status of Qads was negative, which showed that there was a flow of heat from the inhibitor-mild-steel interface of seemingly higher temperature to the surroundings of lower temperature. The adsorption of the inhibitors’ molecules was physical, not chemisorption, and Langmuir isotherm was the best fit.
* quadratic model adequately described relationships between efficiency and factors of inhibitor and optimum efficiency of 93.27% was attained. ANN gave better optimization result than the RSM because ANN had higher R2 and lower RMSE and SEP.
* From the results of electrochemical impedance spectroscopy, the charge-transfer process was controlled. promethazine-theoclate was seen as mixed-type inhibitor in corrosive media.

**ETHICAL STATEMENT**

This research received ethical approval, and complied with the guidelines and regulations of the studies. Informed consent was obtained from all participants. Human participants involved in the study include only the authors: Linda Nnodi, Ifeanyi John Obibuenyi, Okechukwu Joseph Ezeugo, Okechukwu Dominic Onukwuli, Ikechukwu A, Nnanwube and C. B. Ezekannagha.

* Therefore, research has been conducted with the highest standards for rigor and integrity.
* The article study is original.
* This work has not been submitted elsewhere and is not under consideration for publication elsewhere.
* The work does not include libelous, defamatory or unlawful statements.
* There was no third-party material(s) included.
* Proof of consent has been obtained for any named individuals or organizations.
* Authorship has been agreed prior to submission and no one has been ‘gifted' authorship or denied credit as an author (ghost authorship).

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