

INVESTIGATION OF THE INHIBITIVE EFFECT OF 1,8-NAPHTHYRIDINE DERIVATIVES ON CORROSION OF MILD STEEL IN ACIDIC MEDIA

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ABSTRACT

In the present investigation 1,8-naphthyridine compounds have been synthesized and its inhibition action on the corrosion of mild steel in 1M HCl was investigated by corrosion weight loss test, electrochemical impedance spectroscopy, potentiodynamic polarization and solution analysis techniques (AAS). Polarization measurements clearly indicate that the examined compounds acts as mixed inhibitors and the inhibition efficiency increases with inhibitor concentration. Changes in the impedance parameters (R_{ct} and C_{dl}) are indicative of the adsorption of naphthyridine compounds on the metal surface, leading to the formation of protective film. Solution analyses were carried out by atomic absorption spectroscopy, which shows decreased dissolution of iron in the presence of inhibitors. Physical adsorption is proposed for the inhibition and the process followed the Langmuir adsorption isotherm.

Keywords: 1,8-Naphthyridines, Mild steel, Impedance, Polarization, Atomic absorption spectroscopic method.

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INTRODUCTION

Corrosion of mild steel in acidic aqueous solution is one of the major areas of concern in many industries wherein acids are used for applications such as acid pickling, acid cleaning, acid descaling and oil well acidizing. The loss of metals as a result of its contact with acids can be minimized by the use of inhibitors¹.

Most of the well known acid inhibitors are organic compounds containing nitrogen, sulphur and oxygen atoms. It has been reported that many heterocyclic compounds containing N, O, and S have been proved to be effective inhibitors for the corrosion of mild steel in acid media²⁻⁴. It is generally accepted that the presence of N-heterocyclic compounds exert their adsorption on the metal surface through N heteroatom, as well as those with triple or conjugated double bonds or aromatic rings in their molecular structures. Furthermore, the adsorption of inhibitor on the steel/solution interface is influenced by the chemical structure of the inhibitor, the nature and charged surface of metal, the distribution of charge over the whole inhibitor molecule and the type of aggressive media.

In the present work an attempt has been made to synthesize derivatives of 1,8-Naphthyridine compounds (Table-1) and their anticorrosive property towards mild steel in 1M HCl was evaluated using electrochemical and non-electrochemical methods. The chemical structures of the synthesized compounds were characterized by FTIR spectroscopy.

EXPERIMENTAL

Weight loss method

The pre-weighed polished plates were immersed in 100 ml of 1M HCl containing various concentrations of inhibitors. After a period of three hours, the specimens were washed in running water, dried and

weighed. A blank was also performed simultaneously. From the weight loss values, the inhibition efficiencies and corrosion rate were calculated.

The effect of temperature on the corrosion rate and inhibitor efficiency was studied by repeating the experiment at different temperature ranges 30, 40, 50 and 60 °C using thermostat for the same concentration of the inhibitors.

From the weight loss data the inhibition efficiency, corrosion rate and the surface coverage were calculated using the following formulas-

$$\text{Efficiency of inhibitor} = \frac{(\text{Weight loss without inhibitor} - \text{Weight loss with inhibitor})}{\text{Weight loss without inhibitor}} \times 100 \quad (1)$$

$$\text{Corrosion rate (mpy)} = \frac{534 \times \text{Weight loss in mgms}}{\text{Density} \times \text{Area in sq. inch} \times \text{Time in hours}} \quad (2)$$

$$\text{Surface coverage}(\theta) = \frac{(\text{Weight loss without inhibitor} - \text{Weight loss with inhibitor})}{\text{Weight loss without inhibitor}} \quad (3)$$

From the values of (θ), a graph was drawn between C/θ vs C or θ vs $\log C$ to obtain the best adsorption isotherm.

The activation energy (E_a) was calculated by graphical method by plotting \log (corrosion rate) Vs $1000/T$ (K) for higher temperature of 30, 40, 50 and 60 °C in 1M H_2SO_4 and 1M HCl with and without inhibitor at the concentration of 0.3 mM. Activation energy (E_a) was calculated using the formula-

$$E_a = 2.303 \times 8.314 \times \text{slope (kJ)}$$

The free energy of adsorption ΔG_{ads}° has been calculated from the equilibrium constant of adsorption using the equation-

$$k = \frac{1}{55.5} \exp \left[-\frac{\Delta G_{ads}^\circ}{RT} \right] \quad (4)$$

Where, $k = \frac{\theta}{C(1-\theta)}$ (From Langmuir equation)

θ = Surface Coverage of the inhibitor

C = Concentration of the inhibitor in mM/100ml

and $\Delta G_{ads}^\circ = -RT \ln(55.5k)$ (5)

The entropy and enthalpy of activation was calculated by graphical method by plotting \log (corrosion rate/ T) Vs $1000/T$ for a temperature range of 30-60 °C in 1M HCl with and without inhibitor at 0.30mM. Straight lines were obtained with an intercept $(\ln R/Nh) + \Delta S^\circ/2.303R$ and slope with $\Delta H^\circ/R$. From that, ΔS° and ΔH° were calculated.

$$\Delta S^\circ = (\text{intercept} - \ln R/Nh) R \quad (6)$$

$$\Delta H^\circ = \text{Slope} \times R \quad (7)$$

Electrochemical studies

Electrode surface preparation

The mild steel electrodes used for the polarization and impedance studies had the same composition as that used for weight loss studies with an exposed area of 0.9078 cm². The surface of the electrode was polished using 1/0, 2/0, 3/0 and 4/0 emery papers and finally degreased using trichloroethylene and immediately used for the experiments.

Electrode cell assembly

The electrochemical measurements were carried in a glass cell with a capacity of 100ml. A platinum electrode and a saturated calomel electrode (SCE) were used as counter and a reference electrode. The

mild steel electrode was then placed in the test solution (uninhibited and inhibited) for 10–15 minutes before electrochemical measurements.

Electrochemical study

Electrochemical impedance spectroscopy (EIS) and Tafel polarization were performed using PARSAT-2273. The EIS measurements were made at corrosion potential over a frequency range of 20 MHz to 100 MHz with signal amplitude of 10mV. The Tafel polarization measurements were made after EIS for a potential range of -200 to +200 with respect to open circuit potential at a scan rate of 1mV/sec. From the Nyquist plot (Z_{real} Vs $Z_{\text{imaginary}}$) electrochemical resistance R_t and double layer capacitance C_{dl} were calculated. Corrosion potential E_{corr} , Corrosion current I_{corr} and Tafel's slope for the cathodic and anodic reaction b_c and b_a were obtained from the plot of E Vs $\log I$. Inhibition efficiency by potentiodynamic polarization method:

The inhibition efficiency was calculated from the value of I_{corr} by using the formula-

$$\text{Inhibition efficiency (\%)} = \frac{I_{\text{corr}(\text{blank})} - I_{\text{corr}(\text{inh})}}{I_{\text{corr}(\text{blank})}} \times 100 \quad (8)$$

Where,

$I_{\text{corr}(\text{blank})}$ = The corrosion current in the absence of inhibitor

$I_{\text{corr}(\text{inh})}$ = The corrosion current in the presence of inhibitor

Inhibition efficiency by AC impedance method:

The inhibitor efficiency was calculated using the formula,

$$\text{Inhibition efficiency (\%)} = \frac{R_{t(\text{inh})} - R_{t(\text{blank})}}{R_{t(\text{inh})}} \times 100 \quad (9)$$

Where,

$R_{t(\text{inh})}$ = The charge transfer resistance in the presence of inhibitor

$R_{t(\text{blank})}$ = The charge transfer resistance in the absence of inhibitor

Atomic absorption spectrophotometric studies

Atomic absorption spectrophotometric (model GB 908/AUSTRALIA) was used for estimating the amount of dissolved iron in the corroding solution containing various concentrations of the inhibitors, after exposing the mild steel specimen for three hours. From the amount of dissolved iron the inhibition efficiency was calculated.

$$\text{Inhibition efficiency (\%)} = \frac{B - A}{B} \times 100 \quad (10)$$

Where, A is the amount of dissolved iron in the presence of inhibitor and B is the amount of dissolved iron in the absence of inhibitor.

RESULTS AND DISCUSSION

Weight loss method

Weight loss, percentage inhibition efficiencies, corrosion rate and surface coverage for different concentrations of the inhibitors in 1M HCl are given in (Table-2).

- The plot of weight loss Vs inhibitor concentration. It is clear from the figure that the weight loss decreases with increase in the inhibitor concentration, suggesting an increase in the number of molecules adsorbed on the mild steel surface, blocking the active sites of acid attack and thereby protecting the metal from corrosion.
- It can be seen that the inhibition efficiency of inhibitor increases with increasing concentration of inhibitors. The maximum inhibition efficiency was obtained at an inhibitor concentration of 0.3 mM for N3 (99.21%) and N1 (98.07%). The inhibition efficiencies are found to depend on the inhibitor concentration and the nature of the substituents.

- Decrease in corrosion rate with increase in inhibitor concentration. The high inhibition efficiency of the inhibitors may be due to the presence of $-C-N$, $-OCH_3$, $-N(CH_3)_2$, which are electron rich centers and π electrons of naphthyridine moiety causes strong adsorption on the metal surface.

Effect of temperature and thermodynamic parameters

The effects of temperature on the corrosion behavior of mild steel were studied using weight loss measurements. The results obtained from (Table-3) reveal that there is progressive increase in weight loss as the temperature increases from 303-333 K. This signifies that the dissolution of metals increased at higher temperature.

The increase in the weight loss with increasing temperature may be due to increase in the rate of diffusion and ionization of reacting species in the corrosion process as temperature increases. Also an increase in temperature increases the solubility of the protective films on the metal, thus increasing the susceptibility of the metal to corrosion⁵.

Arrhenius plots for the corrosion rate of mild steel with and without the inhibitors are given in (Fig.-1). The E_a values calculated are presented in (Table-4). It has been proposed⁶ that low activation energy of the process in the presence of inhibitor compared to its absence is attributed to chemisorptions, while the opposite is attributed to physical adsorption. The value of E_a in the absence of inhibitor in 1M HCl is 45.63 kJ, and the values were found to increase in the presence of inhibitors indicating the physical or weak bonding between the molecules of the inhibitor and mild steel surface.

The standard free energy of adsorption ΔG°_{ads} was calculated using the relation,

$$k = \frac{1}{55.5} \exp \left[-\frac{\Delta G^\circ_{ads}}{RT} \right] \quad (11)$$

and the values are given in (Table-4). The negative values of ΔG°_{ads} ensure the spontaneity of the adsorption process and the stability of adsorbed layer. Generally the values of ΔG°_{ads} of -20 kJ mol^{-1} are consistent with physisorption, while those around -40 kJ mol^{-1} are associated with chemisorptions as a result of the sharing or transfer of electrons from organic molecules to the metal surface to form a coordinate bond⁷. The observed values of ΔG°_{ads} were around -17 to -25 kJ mol^{-1} indicating that the adsorption of inhibitor is physisorption based mechanism. The adsorption is enhanced by the presence of nitrogen atoms with lone pair of electrons and the delocalized π electrons in the inhibitor molecules that make it adsorbed electro statically on the metal surface thus decreasing metal dissolution.

The experimental corrosion rate values obtained from weight loss measurements in 1M HCl in the presence and absence of inhibitors was used to further gain insight on the change in enthalpy (ΔH°) and entropy (ΔS°) of activation for the formation of the activation complex in the transition state using the equation,

$$\text{Corrosion rate} = \frac{RT}{Nh} \exp \left[\frac{\Delta S^\circ}{R} \right] \exp \left[\frac{\Delta H^\circ}{RT} \right] \quad (12)$$

The relationship between $\log (CR/T)$ and $1/T$ is shown in (Fig.-2). Straight lines are obtained with a slope of $(-\Delta H^\circ/2.303R)$ and an intercept of $[\log(R/Nh) + (\Delta S^\circ/2.303R)]$, from which the value of ΔH° and ΔS° were calculated and presented in (Table-4). The value of $\Delta H^\circ > 10 \text{ kJ/mole}$ is probably due to chemisorptions and $\Delta H^\circ < 10 \text{ kJ/mole}$ implies physisorption⁸. The more negative values of ΔH° indicate that the adsorption of inhibitor molecules is an exothermic reaction, resulting in physical adsorption.

On comparing the values of ΔS° , it is clear that entropy of activation increased in the presence of inhibitors compared to free acid. Such variation is associated with the phenomenon of ordering and

disordering of inhibitor molecules on the mild steel surface⁹⁻¹⁰. The increased entropy of activation in the presence of inhibitors indicated that disorderness is increased ongoing form reactant of activated complex, which may be attributed to desorption of the molecules from the mild steel surface leading to randomness.

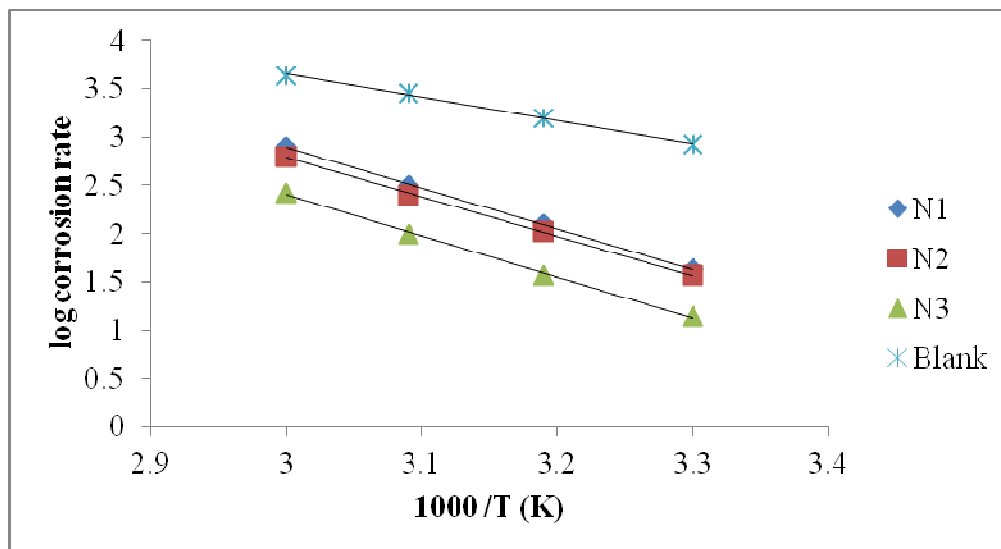


Fig.-1: Arrhenius plot of corrosion of mild steel in 1M HCl solution on the absence and presence of inhibitors.

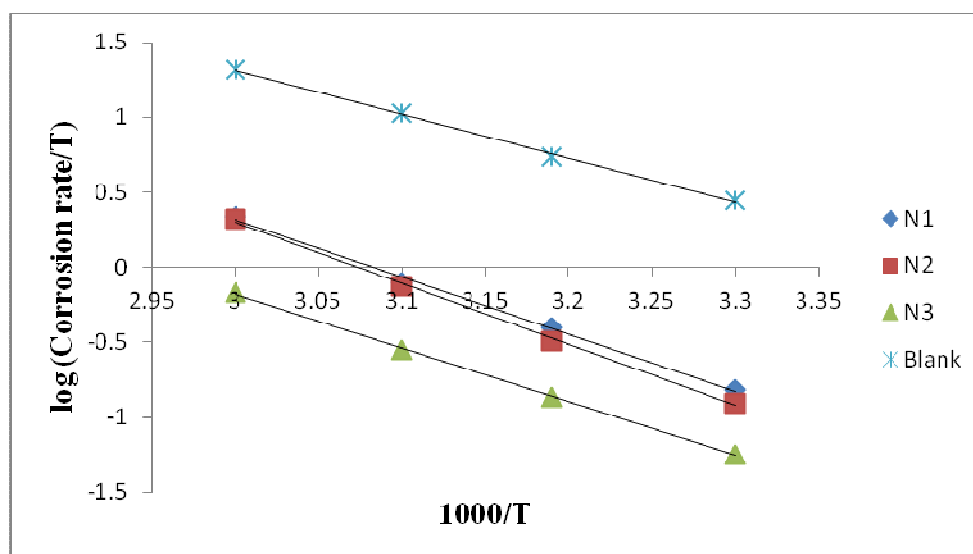


Fig.-2: Transition state plot for mild steel corrosion in 1M HCl in the absence and presence of 0.3 mM concentration of the inhibitor.

Adsorption isotherm

Adsorption mainly depends on the charge of the metal surface, electronic characteristics of the metal surface, adsorption of solvent and other ionic species, temperature of corrosion reaction and on the electrochemical potential at solution-interface. Adsorption of inhibitor involves the formation of two

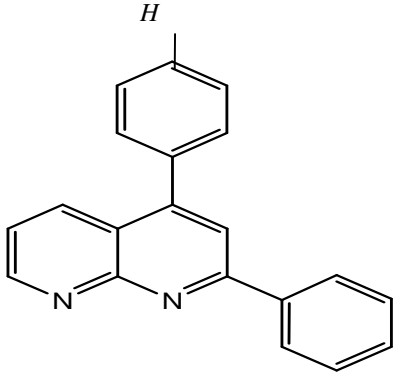
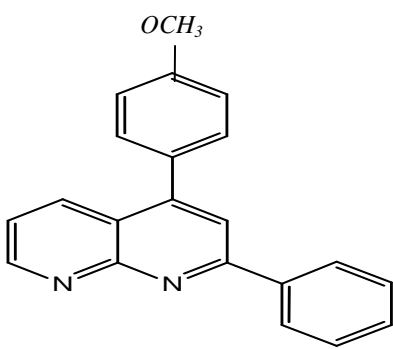
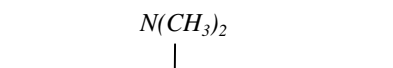
types of interactions responsible for bonding of inhibitor to the metal surface. The first one is the physical adsorption, is due to electrostatic attraction between the inhibiting organic ions or dipoles and the electrically charged surface of metal. The second type of interaction occurs when directed forces govern the interaction between the adsorbate and adsorbent. Chemical adsorption involves charge sharing or charge transfer from adsorbates to the metal surface atoms in order to form a coordinate bond. The adsorption of the organic molecules occurs as the interaction energy between molecule and metal surface is higher than that between the water molecule and the metal surface¹¹.

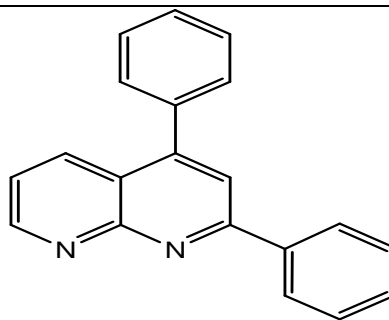
To examine the adsorption behavior of the inhibitor, the experimental data were made to fit with various adsorption isotherms including Langmuir, Frumkin, Temkin, Freundlich, Bockris-Swinkels and Flory-Huggins isotherms. The results were best fitted with Langmuir adsorption isotherm, which is given by-

$$C/\theta = 1/K + C \quad (13)$$

Where K is the equilibrium constant for the adsorption process, C is the concentration of the inhibitor, θ is the degree of surface coverage. The plot of C/θ Vs C is a straight line for all inhibitors (Fig. 3), indicating that the organic molecules are attached on the metal surface through physical mechanism.

Table-1: Name, Structure of the inhibitors used.

Name of the inhibitor	Molecular Structure
2,4-Diphenyl-[1,8]naphthyridine N1	
2,4-Diphenyl-[1,8]naphthyridine N2	
2,4-Diphenyl-[1,8]naphthyridine N3	$N(CH_3)_2$ 



AC impedance measurements

Nyquist plots were recorded for mild steel in uninhibited acid and three selected concentrations of the inhibitor, shown in (Fig. 4). The double layer capacitance (C_{dl}) and the charge transfer resistance (R_{ct}) obtained from EIS measurements are presented in (Table 5). There is a gradual increase in the diameter of each semicircle of the Nyquist plot as the concentration increases from 0.05 to 0.3 mM. The greatest effect was observed at 0.3 mM for N3 which shows a value $63.6 \Omega\text{cm}^2$. The charge transfer resistance value increased with the increase in the inhibitor concentration, this is because at low concentration of 0.05 mM, the molecules are likely to be adsorbed on the metal surface partially and the major part of the surface remained unprotected. With an increase in the additive concentration, the number of molecules adsorbed on the metal surface increases and at the maximum concentration the major part of the metal surface is covered with the inhibitor resulting in increased inhibition efficiency. It is also clear that the impedance diagrams are not perfect semicircles which can be attributed to the frequency dispersion as a result of the roughness and in homogeneity of the electrode surface¹². The values obtained clearly reveals that C_{dl} value decreases with inhibitor concentration. The thickness of the protective film δ_{org} , is related to C_{dl} by the following equation,

$$\delta_{org} = \epsilon_0 \epsilon_r / C_{dl} \quad (14)$$

Where ϵ_0 is the dielectric constant and ϵ_r is the relative dielectric constant.

The decrease in the C_{dl} value is attributed to the decrease in the local dielectric constant/ an increase in the thickness of the electrical double layer, suggesting that the inhibitor act by the adsorption at the metal/solution interface by displacing the water molecules and other ions originally adsorbed on the surface¹³⁻¹⁴.

Potentiodynamic polarization

The potentiodynamic polarization data of various concentrations of the inhibitors are shown as Tafel plots in (Fig.-5). The corrosion kinetic parameters such as corrosion potential (E_{corr}), corrosion current density

(I_{corr}), anodic and cathodic Tafel slopes (b_a and b_c) were derived from the curves and are given in (Table-6). The results clearly indicate that the corrosion current density (I_{corr}) values gradually decreased with increase in the concentration of the inhibitor showing a minimum value for 0.3 mM concentration of N3 from $2766 \mu\text{Acm}^{-2}$ – $298.1 \mu\text{Acm}^{-2}$ with respect to blank. Moreover, there is a significant decrease in the values of both anodic and cathodic Tafel slopes with the increase in the inhibitor concentration showing that the addition of inhibitor modifies the mechanism of the hydrogen reduction as well as decreases the rate of anodic dissolution in all the cases. This means the inhibitors act by blocking both anodic and cathodic sites and behave as mixed-type of acid corrosion inhibitors.

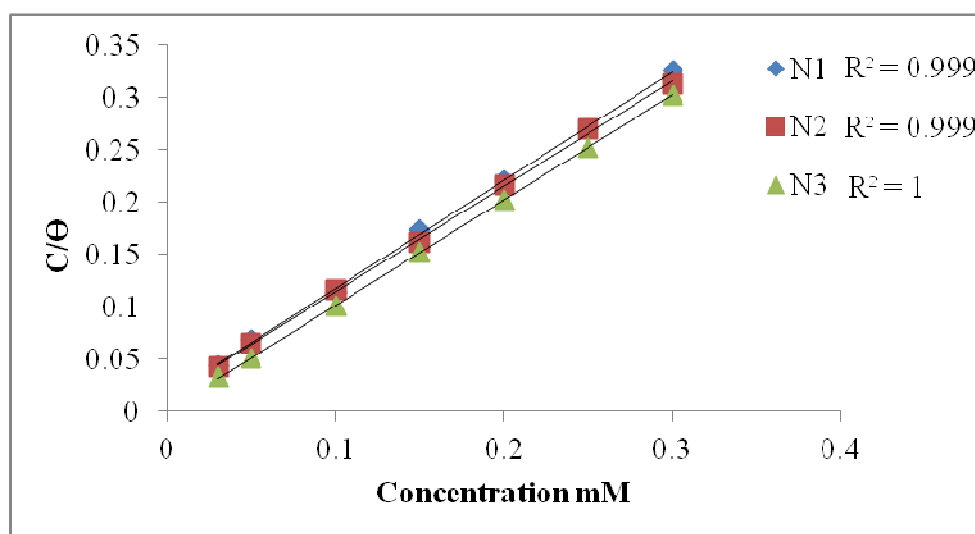


Fig.-3: Langmuir plot of inhibitors in 1M HCl

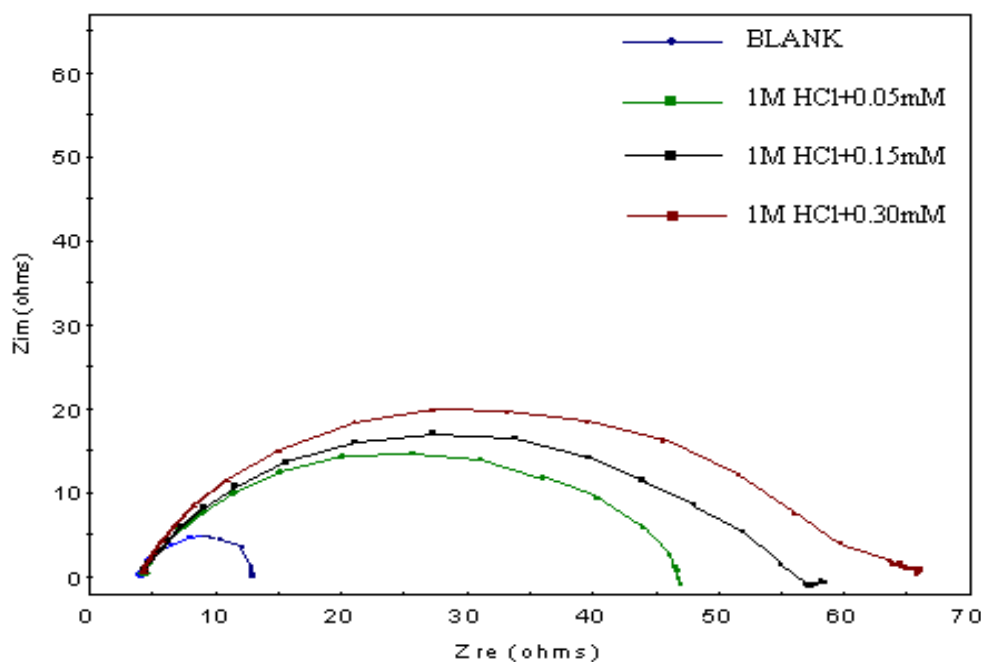


Fig.-4: Nyquist diagram for mild steel in 1M HCl for selected concentrations of N3.

Atomic absorption spectral measurements

Atomic absorption spectroscopic method measures the concentration of ions in the solution. The percentage inhibition efficiency of the inhibitor (N3) towards the dissolution of iron was calculated by measuring the dissolved iron in the corroding solution with and without inhibitor. The results are presented in the (Table 7), which shows that increase in concentration of inhibitor decreases the amount of dissolved iron resulting in increased inhibition efficiency. The percentage inhibition efficiency obtained by this technique was found to be in good agreement with that obtained from the conventional weight.

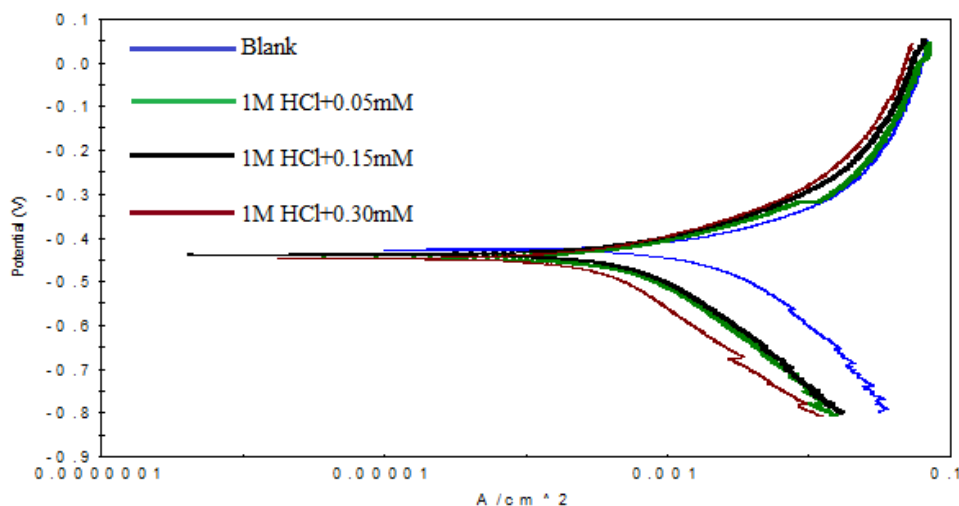


Fig.-5: Polarization curves for mild steel in 1M HCl for selected concentration of inhibitor N3.

Table –2: Inhibition efficiencies of various concentrations of inhibitors on mild steel in 1M HCl by weight loss measurements at room temperature.

Inhibitor concentration (mM)	Weight Loss (g)	Inhibition efficiency (%)	Corrosion Rate (mpy)	Degree of Coverage (Θ)
Blank	0.1398	-	3514.33	-
0.05	0.0390	72.10	0980.39	0.7210
0.15	0.0257	81.62	0646.05	0.8162
0.30	0.0027	98.07	0067.87	0.9807
0.03	0.0420	69.69	1055.81	0.6996
0.15	0.0197	85.91	0495.22	0.8591
0.30	0.0015	98.93	0037.71	0.9893
0.03	0.0120	91.42	0301.66	0.9142
0.15	0.0016	98.86	0040.22	0.9886
0.30	0.0011	99.21	0027.65	0.9921

Evaluation of inhibition efficiency

By comparing the values of inhibition efficiencies obtained from both EIS and weight loss methods with those obtained from Tafel extrapolation method, it is observed that, there is no agreement between these values. These observations have been supported with the findings of Khaled¹⁵ and they attribute this difference between electrochemically and chemically determined rates to the operation of a separate potential independent of chemical dissolution.

The percentage inhibition efficiency values exhibited by the inhibitors are appreciably high. This type of organic compounds function by adsorbing on the metal surface by forming a bond between the N electron pair and the π -electron cloud and the metal thereby reducing the corrosive attack on metals in acidic media¹².

The inhibition efficiency values of the inhibitor are found to lie in the following order-

$$N3 > N2 > N1$$

The substitution of $-OCH_3$, $-N(CH_3)_2$ resulted in different inhibition efficiency values. The substitution of these groups was expected to improve the inhibition efficiency of the parent compound by enlarging the surface area and increasing one more active center in the form of O and N. Variation in the structure of inhibitor molecule takes place through the phenyl group. Hence the inhibition efficiency differences would probably originate from this part of the molecule while the naphthyridine moiety remains constant. This can be explained on the basis of +I and -I effect of the substituents¹⁶. The methoxy group and dimethyl group at the p-position in N2 and N3 acts as an electron donating group and therefore the electron density of the delocalized π electron on the phenyl ring increases¹⁷, which results in the stronger adsorption of the metal surface in the case of N2 and N3. From the analysis of the inhibition efficiency from the (Table 2-7), it is clear that N3 exhibits the maximum inhibition efficiency of 99.21 at 0.3 mM concentration of the inhibitor. This may be due to the presence of 2- CH_3 groups, which enhances the electron density on the nitrogen atom and thereby providing an additional anchoring site for adsorption. The order of decreased inhibition efficiency of these additives can be accounted for in terms of polar effect¹⁸⁻¹⁹ of the substituents on the phenyl ring. Compound N3 is the most efficient inhibitor, because of the presence of $-N(CH_3)_2$ group in the p-position is an electron donating group with negative hammett constant ($\sigma = -0.21$). This group increases the electron charge density on the molecule. Compound N2 comes after N3 in inhibition efficiency, because of the presence of $-OCH_3$ which is an electron donating group with negative hammett constant ($\sigma = -0.27$). Also, this group will increase the electron charge density on the molecule, but with lesser amount than p- $N(CH_3)_2$. Compound N1 with hammett constant $\sigma = 0.00$ comes after compound N2 in inhibition efficiency because H-atom has no effect on the charge density on the molecule.

Table-3: Inhibition efficiencies of 0.3 mM concentration of inhibitor for corrosion of mild steel in 1M HCl by weight loss measurements at higher temperatures.

Name of the inhibitor	Temperature K	Weight loss (g)	Inhibition Efficiency (%)	Corrosion rate (mpy)
N1	303	0.0009	98.07	0067.87
	313	0.0017	84.82	0128.21
	323	0.0034	83.89	0256.41
	333	0.0120	79.17	0904.98
N2	303	0.0005	98.93	0037.71
	313	0.0014	87.50	0105.58
	323	0.0027	87.20	0203.62
	333	0.0098	82.99	0739.06
N3	303	0.0004	99.14	0030.17
	313	0.0005	95.54	0037.71
	323	0.0011	94.79	0082.96
	333	0.0035	93.92	0263.95

CONCLUSIONS

- The studied 1,8-naphthyridine derivatives show a high efficiency towards corrosion of mild steel with increase in the concentration of inhibitor.
- The order of inhibition efficiency of the synthesized compounds is- $N3 > N2 > N1$
- The adsorption of the inhibitor follows Langmuir adsorption isotherm.
- The effect of temperature indicates that the inhibition efficiency decreases with rise in temperature.

- The activation energy (E_a) is higher for inhibited acids than for uninhibited acids showing the temperature dependence of inhibition efficiency.
- The negative value of $\Delta G^\circ_{\text{ads}}$ indicate the spontaneous adsorption of the inhibitor molecules on the metal surface.
- Electrochemical impedance spectroscopy measurements shows that increase in the inhibitor concentration causes an increase in the charge transfer resistance R_{ct} and decrease in C_{dl} value, due to the increased thickness of the adsorbed layer.
- Potentiodynamic polarization curves indicate that all the inhibitors behave as mixed type inhibitors but cathodic effect is more pronounced.

Table-4: Activation energy (E_a), free energy of adsorption ($\Delta G^\circ_{\text{ads}}$) and Thermodynamic Parameters for the corrosion of mild steel in 1M HCl at 0.3 mM concentration of the inhibitors.

Name of the inhibitor	E_a kJ	$-\Delta H^\circ$ kJ/mole	$-\Delta S^\circ$ kJ/mole/K	$\Delta G^\circ_{\text{ads}}$ at various temperature kJ			
				303	313	323	333
Blank	45.63	0.0243	0.1138	-	-	-	-
N1	80.57	0.0315	0.1002	-23.03	-18.04	-18.12	-18.17
N2	77.85	0.0338	0.0936	-24.54	-18.64	-19.17	-18.87
N3	81.61	0.0297	0.1099	-25.35	-21.58	-21.83	-22.06

Table-5: AC impedance parameters for mild steel for selected concentrations of the inhibitor in 1M HCl at $30 \pm 1^\circ\text{C}$.

Name of the inhibitor	Inhibitor concentration (mM)	R_t (Ohm/cm ²)	C_{dl} ($\mu\text{F}/\text{cm}^2$)	Inhibition efficiency (%)
N1	Blank	6.45	38.34	-
	0.05	19.57	24.33	67.04
	0.15	31.42	19.12	79.47
	0.30	42.75	12.76	84.91
N2	0.05	33.4	18.33	80.68
	0.15	44.46	13.73	85.49
	0.30	53.17	8.344	87.86
N3	0.05	43.83	11.44	85.28
	0.15	54.76	7.716	88.22
	0.30	63.6	7.515	89.85

Table-6: Corrosion parameters for the mild steel with selected concentrations of the inhibitor in 1M HCl by potentiodynamic polarization method at $30 \pm 1^\circ\text{C}$.

Name of the inhibitor	Inhibitor concentration (mM)	Tafel slopes (mV/decade)		E_{corr} (mV)	I_{corr} ($\mu\text{A}/\text{cm}^2$)	Inhibition efficiency (%)
		b_a	b_c			
N1	Blank	127.40	248.72	-0.4270	2766.0	-
	0.05	113.05	216.86	-0.4295	895.6	67.62
	0.15	117.32	252.89	-0.4365	555.4	79.88
	0.30	108.20	188.78	-0.4291	424.6	84.64
N2	0.05	105.99	228.30	-0.4812	605.6	78.10
	0.15	103.63	154.06	-0.4767	408.1	85.24
	0.30	100.84	241.18	-0.4751	358.0	87.05
N3	0.05	104.50	233.03	-0.4471	402.5	85.44
	0.15	79.59	223.0	-0.4389	325.1	88.24
	0.30	76.43	253.54	-0.4475	298.1	89.22

Table-7: Amount of dissolved iron present in the corrosive solution (1M HCl) containing selected concentrations of N3 by AAS.

Inhibitor concentration in mM	Amount of iron in corrodant (mg/l)	Inhibition efficiency (%)
Blank	356.95	-
0.05	18.2212	94.40
0.15	12.0313	96.63
0.30	11.7669	96.70

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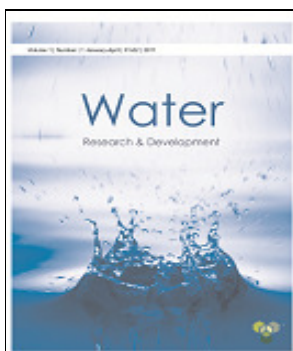
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