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Study of Corrosion Inhibition Activities of N-(4-Methoxyphenyl)5(Pyridin4-Yl)- 1,3,4-Oxadiazol-2-Amine Hemi Hydro-Chloridemono Hydrate for Mild Steel in 1 N Hcl

Rahul Mishra[1] **and Chitrasen Gupta**[2]

[1,2]*Department of chemistry, Kutir P.G. College, Chakkey, Jaunpur-222146, U.P. India*

Corresponding Author:** ***Chitrasen Gupta*, Department of chemistry, Kutir P.G. College, Chakkey, Jaunpur-222146. U.P. India.*

Abstract

This work reports the synthesis and evaluation of two novel heterocyclic compounds, potassium (I) 5-(2-methylpyridin-4-yl)-1, 3, 4-oxadiazole-2-thiolate (KMPOT) and N'-(2-hydroxybenzylidene)-2-methylisonicotinohydrazide (HMIH), as corrosion inhibitors for mild steel in 1 N HCl medium. The inhibitors were characterized using elemental analysis, FT-IR, and 1H NMR spectroscopy. The corrosion inhibition efficiency was studied using weight loss measurements, potentiostatic polarization, electrochemical impedance spectroscopy (EIS), and scanning electron microscopy (SEM). Weight loss results revealed maximum inhibition efficiencies of 94.6% for KMPOT and 92.7% for HMIH at 500 ppm and 30 °C. Potentiodynamic polarization indicated that both inhibitors act as mixed-type inhibitors with a predominant cathodic effect. EIS studies confirmed adsorption of inhibitors on the steel surface and increased charge transfer resistance, consistent with Langmuir adsorption isotherm. SEM analysis further validated surface protection in the presence of inhibitors. Overall, both compounds exhibit promising potential as efficient and eco-friendly corrosion inhibitors for acid pickling and industrial applications.

Keywords: *Corrosion Inhibitor, synthesis, inhibition efficiency, industrial application.*

1. INTRODUCTION

Corrosion of mild steel in acidic environments, particularly hydrochloric acid, is a long-standing industrial challenge with serious economic and safety implications. In sectors such as acid pickling, descaling, pipeline cleaning, and oil well acidizing, hydrochloric acid is widely used to remove scale, rust, and other corrosion products from steel surfaces. However, such processes accelerate the degradation of steel, leading to material loss, reduced mechanical integrity, and significant maintenance costs [1]. To mitigate these issues, the use of organic corrosion inhibitors has proven to be one of the most effective and cost-efficient strategies [2].

Organic inhibitors generally function by adsorbing onto the metal surface to create a protective film, which impedes the electrochemical processes of corrosion — namely the anodic dissolution of iron and cathodic hydrogen evolution. The efficiency of adsorption and protection depends on the inhibitor's molecular structure: presence of heteroatoms (such as N, O, S), π-electron systems, aromatic rings, electron-donating substituents, and functional groups that can coordinate to metal atoms [3]. Additionally, temperature, concentration, and pH of the corrosive medium crucially affect inhibition behaviour [4].

Heterocyclic compounds, including oxadiazoles, hydrazones, triazoles, etc.,not used in field of medicine, agriculture, water remediation and polymer but also widely investigated for their corrosion inhibition potential[5-12]. For example, **1**,3,4-oxadiazole-pyridine hybrids have demonstrated high inhibition efficiencies (~97–98 %) for mild steel in 1 N HCl via weight loss, electrochemical impedance spectroscopy (EIS), potentiodynamic polarization (PDP), and surface characterization, acting as mixed-type inhibitors [13]. Hydrazone derivatives similarly show strong inhibition effects: Chaouiki et al. synthesized hydrazone inhibitors which achieved up to ~96 % protection of mild steel in 1.0 M HCl (using weight loss, PDP, EIS, and SEM-EDX) and demonstrated that their adsorption follows the Langmuir isotherm [14].

Despite these advances, there remains room for development of new inhibitors with higher efficiency, better thermal stability, lower toxicity, and more durable protective films under harsh conditions. Differences in molecular structure, such as inclusion of thiolate or other strong coordinating groups, can improve electron donation to the steel surface, strengthen chemisorption, and thus improve inhibition, especially at elevated temperatures or over extended immersion times [15].

In the present work, we synthesize two new inhibitors — potassium (I) 5-(2-methylpyridin-4-yl)-1, 3, 4-oxadiazole-2-thiolate (KMPOT) and N′-(2-hydroxybenzylidene)-2-methylisonicotinohydrazide (HMIH) — and evaluate their corrosion inhibition performance on mild steel in 1 N HCl. We assess inhibition efficiency by weight loss, potentiostatic polarization, and EIS. Additionally, we examine surface morphology using scanning electron microscopy (SEM) to elucidate the protective film formed. Our goal is to compare the two synthesized inhibitors, understand their mechanisms of adsorption, determine how they affect anodic and cathodic reactions, and assess their potential for practical acid corrosion protection applications.

2. MATERIAL AND METHODS

All the chemical was purched from Merck and SD-Fine. These chemicals were used directly without any purification.

2.1. Acid Solutions for Corrosion Test

To prepare solutions with a 1N concentration of acid, analytical-grade HCl was diluted using distilled deionized water. Two to three milliliters of pure ethanol were added to completely dissolve the inhibitors.

2.2. Test Specimen

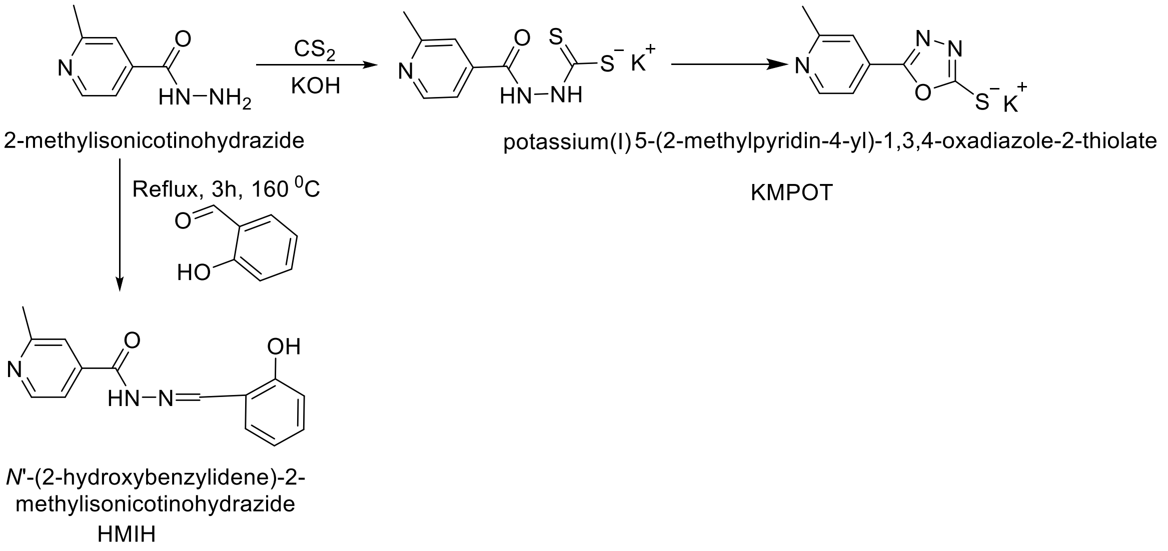
Composition of mild steel: C = 0.14, Mn = 0.33, Si = 0.21, S = 0.019, P = 0.02, Fe = 99.21

2.3. Synthesis of KMPOT

Potassium(I) 5-(2-methylpyridin-4-yl)-1,3,4-oxadiazole-2-thiolate, referred to as KMPOT, was synthesized by gradually adding carbon disulfide (1.5 ml, 20 mmol) to a suspension of 2-methyl isonicotinohydrazide (3.12g, 20 mmol) in methanol (20 mL) with potassium hydroxide (1.2g, 20 mmol). The mixture was stirred continuously for 40 minutes, resulting in the formation of a dirty solid, which is the potassium salt of 2-(2-methylisonicotinoyl) hydrazine-1-carbodithioate. This product was then filtered, washed with ethanol, and dried. The obtained solid, which had impurities, was dissolved in a water and ethanol mixture (1:1), leading to a clear solution that was left to crystallize. After 36 hours, white crystals of KMPOT were obtained (see Scheme 1). The yield was 55%, and melting point was 188 ºC.

2.4. Synthesis of HMIH, N'-(2-Hydroxybenzylidene)-2-Methylisonicotinohydrazide

This compound was synthesized by refluxing equimolar mixthure of 2-methyl isonicotinohydrazide and salicyldehyde in ethanol for 3 hours and resulting reaction mixture was poured in 100 g crushed ice. The resu;lting solid was filtered, washed and crystallized with ethanol (Scheme1)Yield 68%, Melting point 199^{0C}



2.5. Study of Corrosion Inhibition Efficiencies

Corrosion inhibition efficiencies of synthesized inhibitors evaluated by utilizing (i) the weight loss method, (ii) the potentiostatic polarization technique, (iii) scanning electron microscopy (SEM)[16]

3. RESULTS AND DISCUSSION

3.1. Characterization of KMPOT, HMIH

The synthesized inhibitors KMPOT and HMIH were characterized by elemental analysis, FT-IR and H-NMR spectral data

3.1.1. Characterization of KMPOT

Chemical formula	M.P.	Colour	Molecular Mass	Elemental Analysis Observed(Calculated)
$C8H6KN3OS$	188^{oC}	White	231.31	C= 41.45(41.54); H= 2.55(2.61); K=15.90(16.90) N=18.11 (18.170, O= 6.89(6.92), S= 13.78 (13.86)

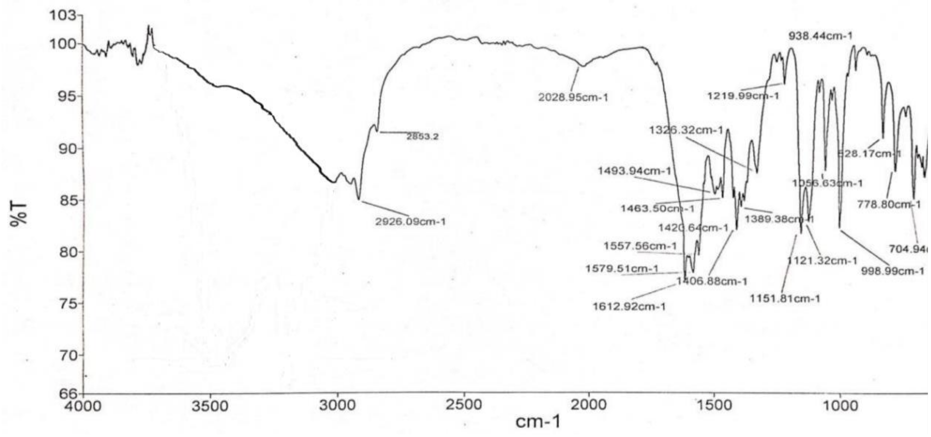


Fig.1. *I.R. spectrum of KMPOT*

Characteristic I.R. bands (KBr disc). 3115cm^{-1}, 3086cm^{-1} , 2926 cm^{-1} CH str.),2028cm^{-1},1612 cm^{-1}, 1579cm^{-1},1557cm$^{-1,}$ 1389cm^{-1} (C=O,C=C,.)1219 cm^{-1}, 1151cm^{-1}, 1056cm^{-1}, 778 cm^{-1} **H^{1}NMR:** 8.24 (CH, Py), 8.88(CH,Py),7.83(CH,Py), 2.68(CH3)

3.1.2. Characterization of HMIH

Chemical formula	M.P.	Colour	Molecular Mass	Elemental Analysis Observed(Calculated)
$C14H13N3O2$	199^{oC}	Light yellow	255.28	C=65.21(65.87), H=5.11 (5.13), N= 16.46(16.34), O= 12.53(12.52)

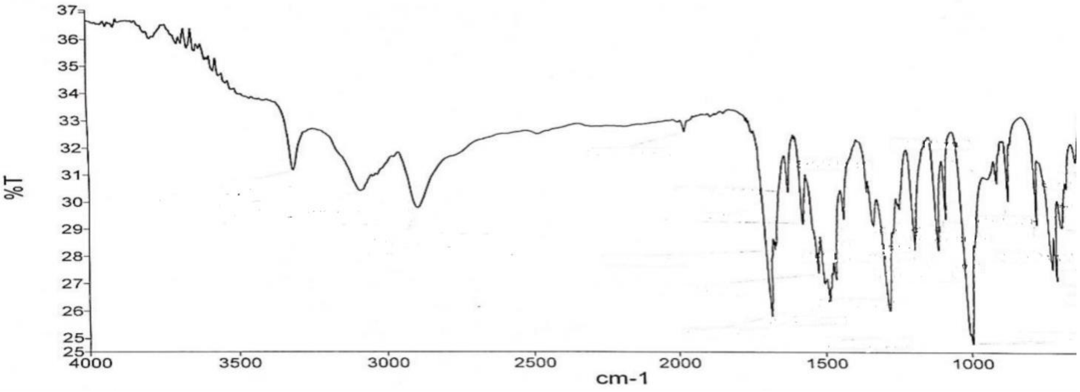


Fig.2. *I.R. spectrum of HMIH*

Characteristic I.R. bands (KBr disc): 3360.10cm^{-1}, 32124cm^{-1} (OH str.)3010cm^{-1} (NH), 2970 CH str.),1685cm1,1655cm^{-1}, 1512cm^{-1},1373cm^{-1} (C=O,C=C,.C=N)1251 cm^{-1}, 1210cm^{-1}, 1113cm^{-1}, 749 cm^{-1} **H^{1}NMR:** 10.01(NH), 9.0(OH), 8.55(=CH), 8.45, 7.65,7.32 (Py CH) 7.45,7.32, 7.16, 6.93(Ph CH) 2.8 (CH3)

3.2. Evaluation of Corrosion Inhibition Efficiencies of KMPOT and HMIH in 1nhcl

(1). Weight loss method

These methods evaluate the inhibition efficiency (IE (%)) of inhibitors in an acidic corrosive medium (1NHCl) by comparing weight loss with and without inhibitors **& KMPOT & HMIH**. Inhibition efficiencies can be calculated by using Equation 1.

IE (%) Inhibition Efficiency = (W0-WI / W0) x 100. ----------------- (1)
Weight loss without inhibitors is denoted by W0, while weight loss with inhibitors is denoted by WI.

Corrosion rate: Corrosion rates were calculated by following formula

$$\text{Corrosion Rate (mmpy)}:-\frac{Weight\ Loss\ (in\ ppm)\times 87.6}{A\times T\times D}$$

$$\frac{W\times 87.6}{A\times T\times D}$$

Where: W = Weight loss (in ppm), A = Area of mild steel, T = Time of reaction, D = Density (Constant-7.75 g/Cm^3)

- **Evaluation of corrosion inhibition Efficiencies of KMPOT**

The corrosion inhibition efficiencies and corrosion rate at temperature 30, 40 and 50 degree centigrade are given in Table 1, 2,3and 4 are as following. Figure 3& 4 are exhibited comparable results inhibition efficiencies and rates at different concentrations of inhibitors.

Table 1. *Corrosion parameters from Weight Loss Studies at 30°C*

Immersion Period: 3Hours

Concentration of Inhibitors (ppm)	Weight Loss (mg)	I.E. (%)	Corrosion Rate (mmpy)
BLANK (1N HCl)	188.02	---	34.81
Compound:- KMPOT			
500	10.11	94.62	1.87
400	18.22	90.30	3.37
300	22.15	88.21	4.10
200	28.21	84.99	5.22
100	38.45	79.55	7.11

Table 2. *Corrosion Parameters from Weight Loss Studies At 40°C*

Immersion Period: 3Hours

Concentration of Inhibitors (ppm)	Weight Loss (mg)	I.E. (%)	Corrosion Rate (mmpy)
BLANK (1N HCl)	189.92	---	35.16
Compound:- KMPOT			
500	12.51	93.41	2.31
400	19.16	89.91	3.54
300	24.21	87.25	4.48
200	29.55	84.44	5.47
100	40.27	78.79	7.45

Table 3. *Corrosion Parameters from Weight Loss Studies At 50°C*

Immersion Period: 3Hours

Concentration of Inhibitors (ppm)	Weight Loss (mg)	I.E. (%)	Corrosion Rate (mmpy)
BLANK (1N HCl)	192.97	---	35.72
Compound:- KMPOT			
500	15.02	92.21	2.78
400	22.79	88.18	4.21
300	26.47	86.28	4.90
200	31.87	83.48	5.90
100	43.47	77.47	8.04

Table 4. *Corrosion Parameters from Weight Loss Studies At 100°C*

Immersion Period: 3Hours

Concentration of Inhibitors (ppm)	Weight Loss (mg)	I.E. (%)	Corrosion Rate (mmpy)
BLANK (1N HCl)	196.96	---	36.46
Compound:- KMPOT			
500	28.47	85.54	5.27
400	39.95	79.71	7.39
300	48.68	75.28	9.01
200	59.82	69.62	11.07
100	70.15	64.38	12.98

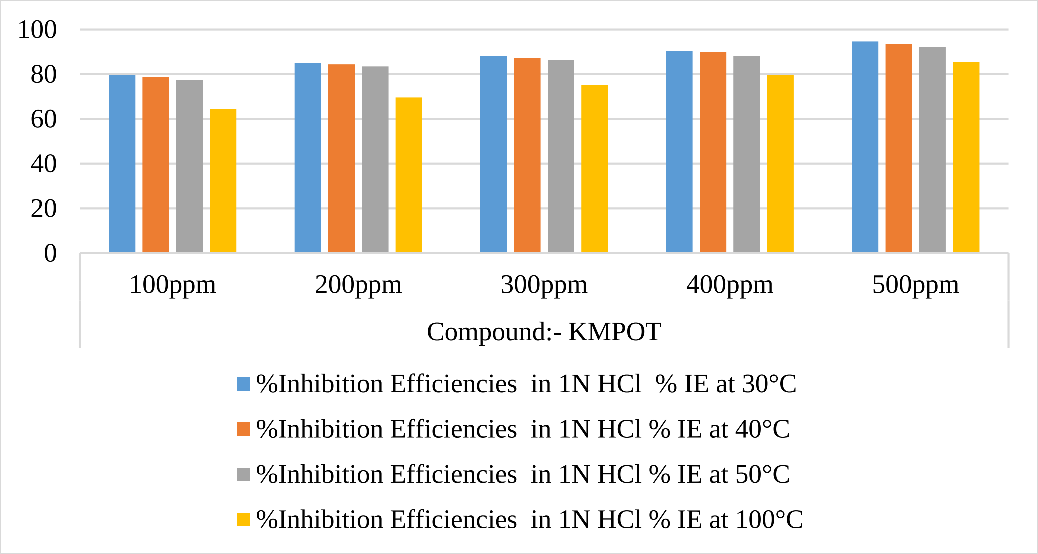


Fig3. *%Inhibition Efficiencies of KMPOTin 1N HCl*

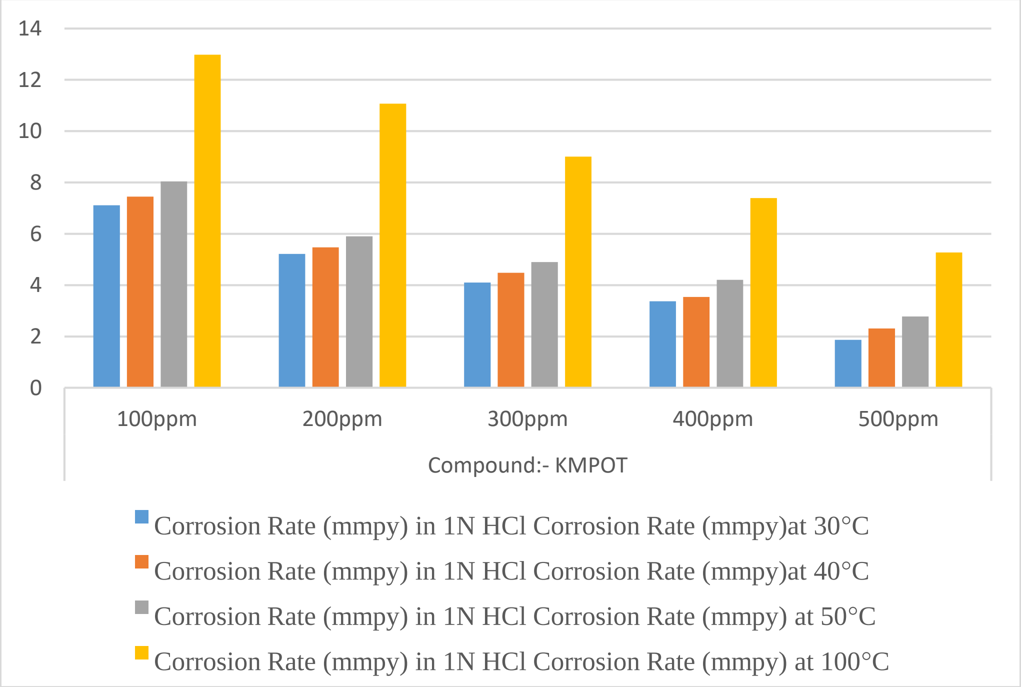


Fig. 4. *Corrosion Rate of KMPOT (mmpy) in 1N HCl*

- **Evaluation of corrosion inhibition Efficiencies of HMIH:** The corrosion inhibition efficiencies and corrosion rate at temperature 30, 40 and 50 degree centigrade are given in Tables5,6,7,and 8 are as following. Figure 5& 6are exhibited comparable results inhibition efficiencies and rates at different concentrations of inhibitors.

Table 5. *Corrosion Parameters from Weight Loss Studies At 30°C*

Immersion Period: 3Hours

Concentration of Inhibitors (ppm)	Weight Loss (mg)	I.E. (%)	Corrosion Rate (mmpy)
BLANK (1N HCl)	180.92	---	33.49
Compound:- HMIH			
500	13.25	92.67	2.45
400	21.96	87.86	4.06
300	26.12	85.56	4.83
200	31.18	82.76	5.77
100	41.92	76.82	7.76

Table 6. *Corrosion Parameters from Weight Loss Studies At 40°C*

Immersion Period: 3Hours

Concentration of Inhibitors (ppm)	Weight Loss (mg)	I.E. (%)	Corrosion Rate (mmpy)
BLANK (1N HCl)	182.12	---	33.71
Compound:- HMIH			
500	15.89	91.27	2.94
400	22.96	87.39	4.25
300	27.89	84.68	5.16
200	33.93	81.36	6.28
100	43.95	75.86	8.13

Table 7. *Corrosion Parameters from Weight Loss Studies At 50°C*

Immersion Period: 3Hours

Concentration of Inhibitors (ppm)	Weight Loss (mg)	I.E. (%)	Corrosion Rate (mmpy)
BLANK (1N HCl)	183.98	---	34.06
Compound:- HMIH			
500	18.99	89.67	3.51
400	25.86	85.94	4.78
300	30.89	83.21	5.71
200	35.93	80.47	6.65
100	46.85	74.53	8.67

Table 8. *Corrosion Parameters from Weight Loss Studies At 100°C*

Immersion Period: 3Hours

Concentration of Inhibitors (ppm)	Weight Loss (mg)	I.E. (%)	Corrosion Rate (mmpy)
BLANK (1N HCl)	186.89	---	34.60
Compound:- HMIH			
500	31.24	83.28	5.78
400	42.92	77.03	7.94
300	51.85	72.25	9.60
200	62.99	66.29	11.66
100	73.25	60.80	13.56

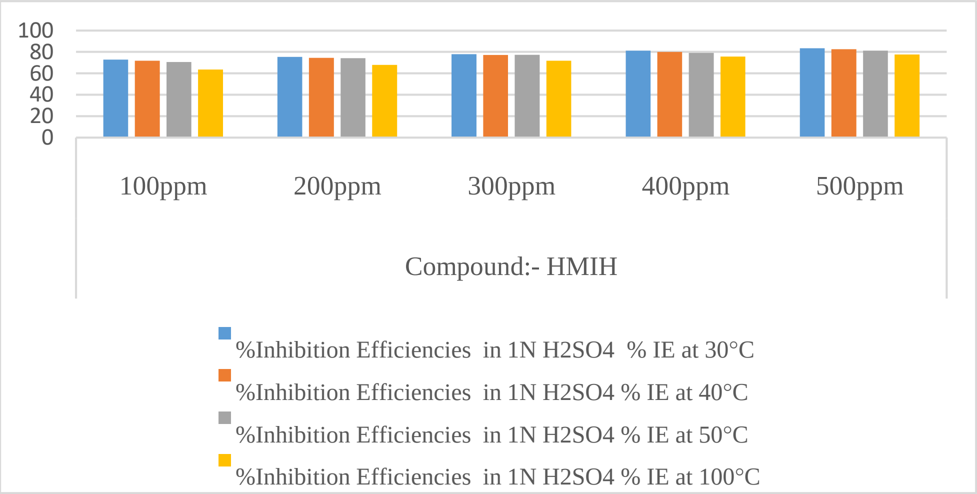


Fig 5. *%Inhibition Efficiencies in 1N HCl*

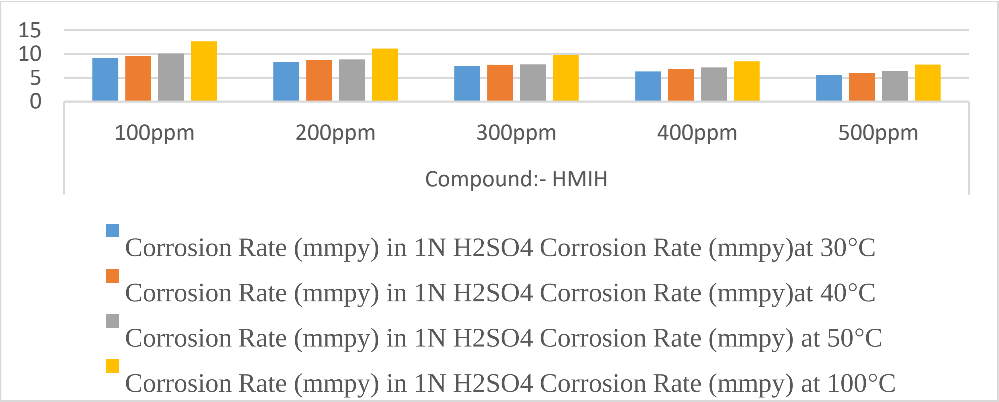


Fig 6. *Corrosion Rate (mmpy) in 1N HCl*

The corrosion inhibition behavior of the synthesized inhibitors KMPOT and HMIH was systematically evaluated in 1 N HCl medium using the weight loss method at different temperatures (30, 40, 50, and 100 °C). The results clearly demonstrate that both compounds act as effective inhibitors for mild steel corrosion, with their efficiencies strongly dependent on inhibitor concentration and temperature (Table1-8).

For both inhibitors, inhibition efficiency (%IE) increased steadily with increasing concentration from 100 to 500 ppm at all studied temperatures. At 30 °C, KMPOT exhibited a maximum inhibition efficiency of 94.62% at 500 ppm, while HMIH reached **92.67%** under identical conditions. This indicates that both molecules significantly reduce the corrosion rate of mild steel in acidic media, but KMPOT provides slightly higher protection compared to HMIH. The decrease in weight loss and corresponding reduction in corrosion rate with increasing concentration suggests the adsorption of inhibitor molecules on the mild steel surface, leading to the formation of a protective film that hinders aggressive chloride ion attack.

A common trend observed for both inhibitors is the decrease in inhibition efficiency with increasing temperature. For KMPOT, %IE decreased from 94.62% (30 °C) to 85.54% (100 °C) at 500 ppm, while for HMIH it dropped from 92.67% (30 °C) to 83.28% (100 °C). Similarly, the corrosion rate increased significantly with temperature in the blank solution (from ~34.8 to 36.5 mmpy for KMPOT sets; 33.5 to 34.6 mmpy for HMIH sets). This behavior indicates that at higher temperatures, the protective inhibitor film becomes less stable due to enhance desorption or breakdown, leading to increased metal dissolution. Thus, the adsorption of both inhibitors appears to follow a physical adsorption mechanism, which is generally less stable at elevated temperatures.

Although both inhibitors show similar inhibition trends, KMPOT consistently outperformed HMIH at all studied concentrations and temperatures. For instance, at 500 ppm and 50 °C, KMPOT maintained 92.21% efficiency with a corrosion rate of 2.78 mmpy, while HMIH showed 89.67% efficiency with a corrosion rate of 3.51 mmpy. The superior efficiency of KMPOT may be attributed to the presence of more effective electron-donating substituents, a larger conjugated system, or a stronger adsorption affinity toward the mild steel surface compared to HMIH.

Interestingly, while higher concentrations enhanced inhibition efficiency at all studied temperatures, the efficiency drop at 100 °C was more pronounced. For instance, KMPOT decreased from 94.62% (30 °C, 500 ppm) to 85.54% (100 °C, 500 ppm), while HMIH dropped from 92.67% to 83.28% under similar conditions. This indicates that temperature has a dominant effect on adsorption stability compared to concentration. However, the fact that both inhibitors maintained above 80% efficiency even at 100 °C suggests strong adsorption capabilities and potential applicability in high-temperature environments.

The corrosion rate values strongly support the inhibition efficiency data. In the absence of inhibitors, the corrosion rate remained high (≈34–36 mmpy across temperatures). Upon the addition of inhibitors, a drastic reduction in corrosion rate was observed, particularly at 500 ppm. At 30 °C, the corrosion rate dropped from 34.81 mmpy (blank) to 1.87 mmpy (KMPOT, 500 ppm) and 2.45 mmpy (HMIH, 500 ppm). Even at 100 °C, the corrosion rate was reduced to 5.27 mmpy for KMPOT and 5.78 mmpy for HMIH at 500 ppm, demonstrating substantial protection efficiency in aggressive acidic medium.

(2). Evaluation of Inhibition Efficiency of corrosion inhibitors by Potentiostatic study

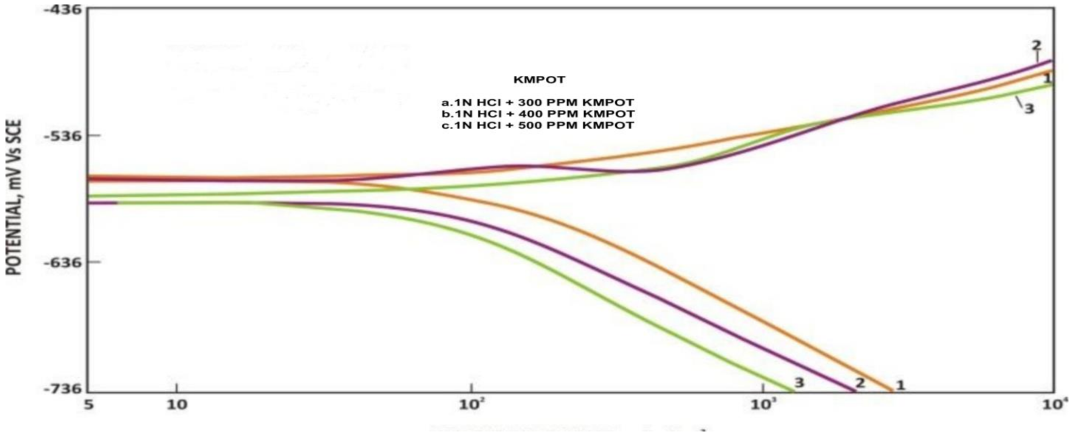


Fig 7. *Potentiostatic study of KMPOT at 300, 400 and 500 PPM*

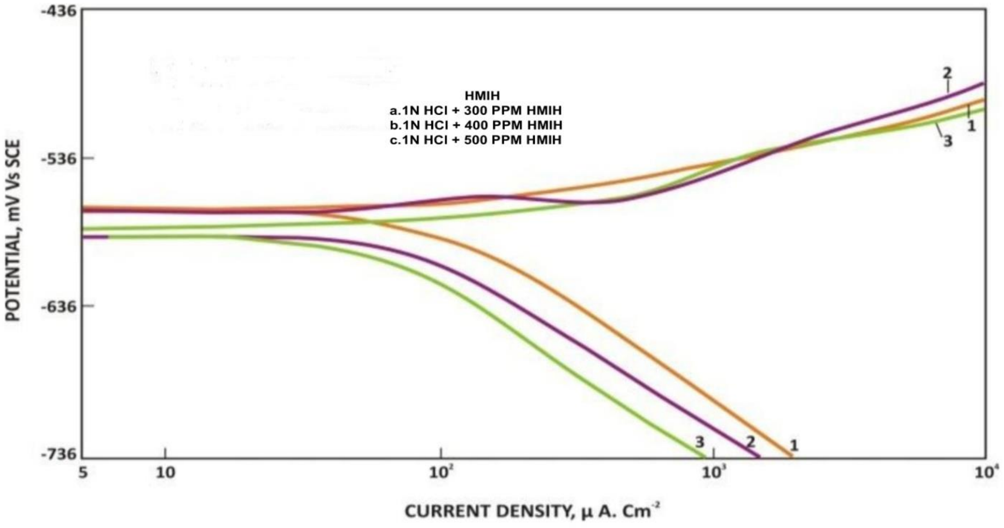


Fig 8. *Potentiostatic study of HMIH at 300, 400 and 500 PPM*

Table 9. *Potentiostatic study of KMPOT and HMIH*

S. No.	Inhibitor (ppm)	KMPOT			HMIH		
		E_{corr}(mV)	I_{corr}(μA.cm^{-2})	IE (%)	E_{corr}(mV)	I_{corr}(μA.cm^{-2})	IE (%)
1.	BLANK	-586	401.25	---	-598	370.77	---
	500 ppm	-565	7.98	98.01	-608	8.95	97.58
	400 ppm	-570	8.55	97.86	-601	11.45	96.91
	300 ppm	-572	11.95	97.02	-599	14.85	95.99

To further validate the inhibition behavior of KMPOT and HMIH, electrochemical (potentiostatic) studies were performed, and the obtained electrochemical parameters are summarized in Table 9**.** The corresponding Tafel polarization curves are presented in Figures 7 and 8**.**

The corrosion potential (Ecorr) values in the absence of inhibitors were recorded at –586 mV (blank) for KMPOT and –598 mV (blank) for HMIH systems. Upon the addition of inhibitors at concentrations of 300–500 ppm, slight shifts in Ecorr were observed for both inhibitors (KMPOT: –572 to –565 mV; HMIH: –608 to –599 mV). These small shifts (<85 mV) suggest that both KMPOT and HMIH act as mixed-type inhibitors, reducing both anodic dissolution of iron and cathodic hydrogen evolution without altering the fundamental corrosion mechanism.

The most notable effect of the inhibitors is the significant decrease in corrosion current density **(**Icorr**)** values. In the blank solutions, Icorr values were 401.25 μA·cm^{-2} for KMPOT and 370.77 μA·cm^{-2} for HMIH. With the addition of 500 ppm inhibitors, Icorr values dramatically decreased to 7.98 μA·cm^{-2} (KMPOT) and 8.95 μA·cm^{-2} (HMIH). Even at 300 ppm, the inhibitors showed pronounced reductions

(11.95 μA·cm⁻² for KMPOT and 14.85 μA·cm⁻² for HMIH), demonstrating strong adsorption of inhibitor molecules and suppression of charge transfer reactions at the metal/solution interface.

The inhibition efficiencies calculated from electrochemical data further confirm the protective ability of both inhibitors. At 500 ppm, KMPOT exhibited an efficiency of 98.01%**,** while HMIH achieved 97.58%**.** At lower concentrations, the efficiencies were slightly reduced but still remained above 95% (Table 9). This superior performance observed in potentiostatic studies is in good agreement with the weight loss results (Tables 1–8), though the electrochemical technique yielded slightly higher inhibition efficiencies, which is typical since electrochemical measurements are more surface-sensitive and reflect instantaneous corrosion processes.

A direct comparison of the two inhibitors reveals that KMPOT again outperforms HMIH across all studied concentrations, albeit marginally. For example, at 300 ppm, KMPOT displayed 97.02% efficiency versus 95.99% for HMIH. This suggests that KMPOT forms a more compact and adherent protective film on the mild steel surface, thereby offering slightly superior corrosion resistance.

(3). Evaluation of Inhibition Efficiency of corrosion inhibitors Electrochemical Impedance Spectroscopy

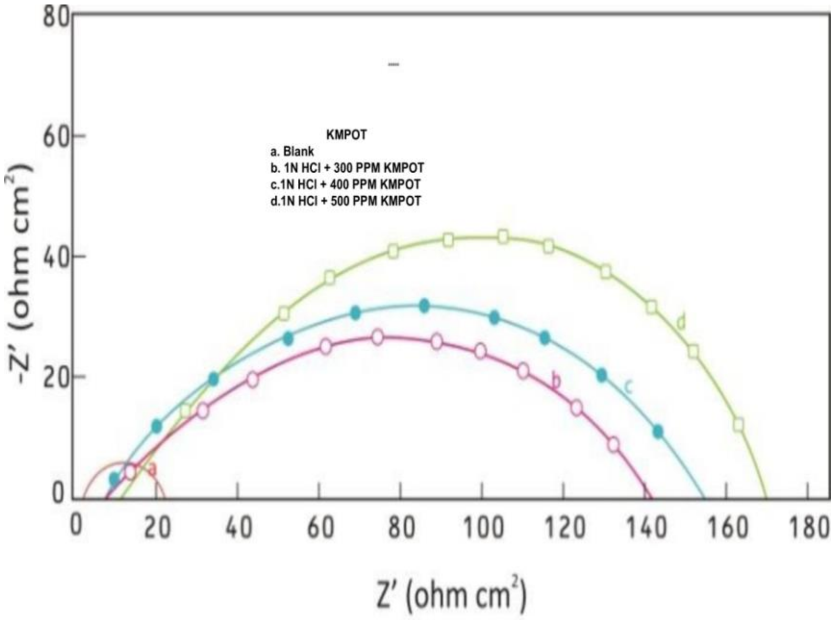


Fig.9. *EIS study of Inhibitor KMPOT in 1NHCl*

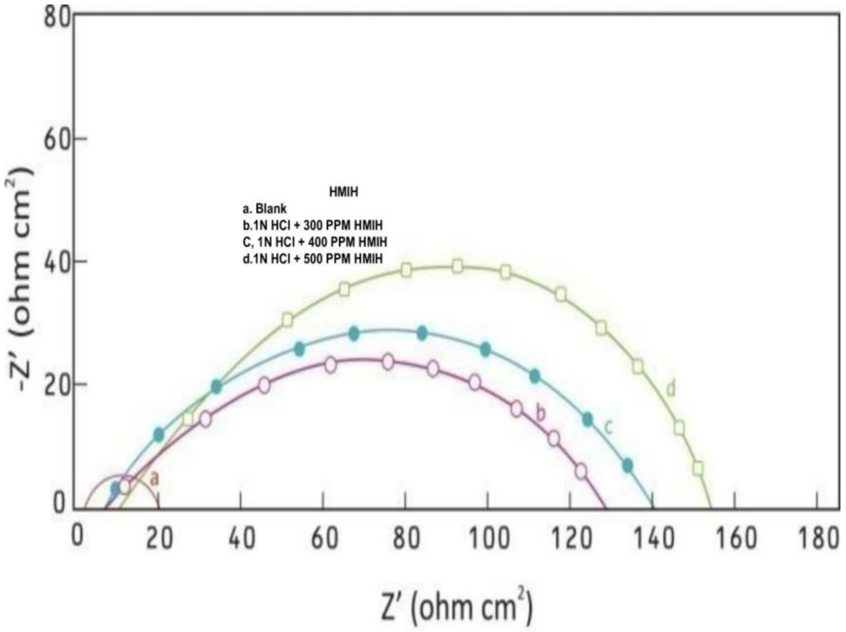


Fig 10. *EIS study of Inhibitor HMIM in 1NHCl*

Table 10. *EIS study of Inhibitor KMPOT and HMIM in 1NHCl*

	Study in 1N HCl					
	KMPOT			HMIH		
	R_t **$Ohm^{-1}.cm^{-2}$**	$I_{corr.}$ **mA.cm-2**	C_{dl} **$F.cm^{-2}$**	R_t **$Ohm^{-1}.cm^{-2}$**	$I_{corr.}$ **$mA.cm^{-2}$**	C_{dl} **$F.cm^{-2}$**
Blank	**19.79**	**2.86**	**915**	**17.95**	**3.57**	**518**
500 ppm	161.22	0.27	394	154.30	0.30	329
400 ppm	149.88	0.29	462	123.50	0.33	382
300 ppm	140.75	0.31	514	113.95	0.37	439

Electrochemical impedance spectroscopy (EIS) was employed to gain further insight into the corrosion inhibition mechanism of KMPOT and HMIH in 1 N HCl solution. The Nyquist plots (Figures 9 and 10) show well-defined semicircles, indicating that the corrosion process is mainly controlled by charge transfer. The corresponding electrochemical parameters, including charge transfer resistance (R**t**), double-layer capacitance (Cdl), and corrosion current density (Icorr), are summarized in Table 10**.**

In the blank solution, Rt values were relatively low (19.79 $\Omega\cdot cm^2$ for KMPOT set; 17.95 $\Omega\cdot cm^2$ for HMIH set), signifying rapid charge transfer and aggressive metal dissolution in 1 N HCl. The introduction of inhibitors led to a substantial increase in Rt, reflecting the formation of a protective film that impedes charge transfer at the steel/solution interface. At 500 ppm, Rt increased to 161.22 $\Omega\cdot cm^2$ (KMPOT) and 154.30 $\Omega\cdot cm^2$ (HMIH), representing nearly an order of magnitude enhancement compared to the blank. This demonstrates the effective adsorption of inhibitor molecules on the steel surface, thereby blocking active corrosion sites. The double-layer capacitance values (**Cdl**) decreased progressively with the addition of inhibitors (from 915 $\mu F\cdot cm^{-2}$ → 394 $\mu F\cdot cm^{-2}$ for KMPOT; 518 $\mu F\cdot cm^{-2}$ → 329 $\mu F\cdot cm^{-2}$ for HMIH at 500 ppm). The reduction in Cdl can be attributed to the replacement of water molecules and aggressive chloride ions by inhibitor molecules at the metal/solution interface, leading to a lower dielectric constant and/or increased thickness of the electrical double layer. This indicates that the inhibitors adsorb strongly on the surface and reduce the available surface area for charge transfer. The Icorr values derived from EIS also confirm the protective effect of the inhibitors. In the blank, Icorr values were relatively high (2.86 $mA\cdot cm^{-2}$ for KMPOT set; 3.57 $mA\cdot cm^{-2}$ for HMIH set). At 500 ppm, these values decreased drastically to 0.27 $mA\cdot cm^{-2}$ (KMPOT) and 0.30 $mA\cdot cm^{-2}$ (HMIH)**.** Even at 300 ppm, significant reductions were observed **(**0.31 $mA\cdot cm^{-2}$ for KMPOT; 0.37 $mA\cdot cm^{-2}$ for HMIH), supporting the adsorption-controlled inhibition process Both inhibitors exhibited similar trends, but KMPOT consistently showed slightly higher Rt values and lower Cdl values compared to HMIH at all studied concentrations. For example, at 400 ppm, KMPOT had Rt = 149.88 $\Omega\cdot cm^2$ and Cdl = 462 $\mu F\cdot cm^{-2}$**,** while HMIH showed Rt = 123.50 $\Omega\cdot cm^2$ and Cdl = 382 $\mu F\cdot cm^{-2}$. This suggests that KMPOT forms a denser, more stable protective film on the steel surface than HMIH.

(4). Scanning Electron Micrposcopy SEM

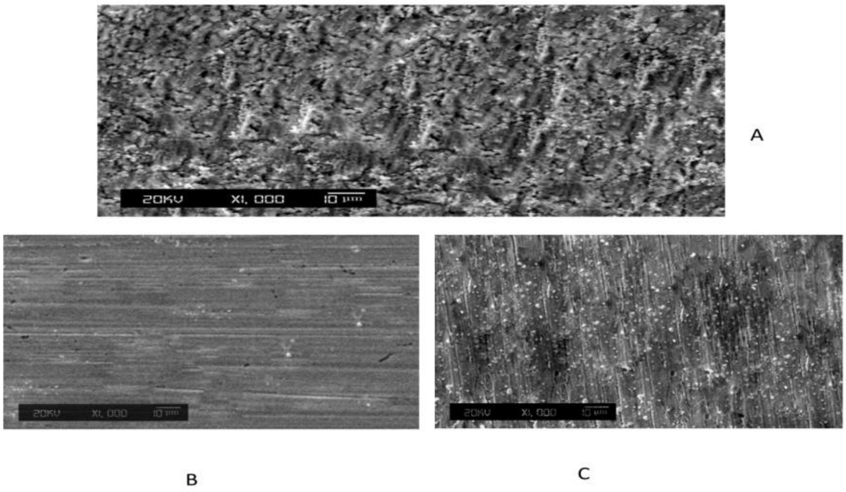


Fig 11. SEM images, A= without inhibitor (Blank)**, B=** KMPOT (500PPM) and IN HCl**, C= HMIH** (500PPM) and IN HCl

To visually support the corrosion inhibition performance of KMPOT and HMIH, surface morphology of mild steel specimens was examined by scanning electron microscopy (SEM). The SEM micrographs are shown in **Figure 11**, where (A) represents the surface in blank 1 N HCl solution, (B) corresponds to the surface with 500 ppm KMPOT, and (C) shows the surface with 500 ppm HMIH.

The SEM image of the blank specimen (Figure 11A) reveals a severely damaged and rough surface. Deep pits, cracks, and irregular corrosion products are evident, confirming intense dissolution of mild steel in the highly aggressive 1 N HCl medium. The porous morphology reflects uncontrolled corrosion attack due to chloride ion penetration and active metal dissolution. In the presence of 500 ppm KMPOT (Figure 11B), the mild steel surface appears significantly smoother and more uniform compared to the blank. The extent of pitting and surface roughness is markedly reduced, with only minor surface defects visible. This demonstrates the effective adsorption of KMPOT molecules onto the steel surface, forming a compact protective barrier that minimizes acid attack. The smoother morphology correlates well with the high inhibition efficiencies obtained in weight loss (Tables 1–4), potentiostatic (Table 9), and EIS (Table 10) studies, where KMPOT consistently provided >90% inhibition efficiency at similar concentrations. The SEM image of the sample treated with 500 ppm HMIH (Figure 11C) also shows significant surface protection compared to the blank. The surface is relatively smooth, with fewer pits and cracks, indicating the adsorption of HMIH molecules and formation of a protective layer. However, compared to KMPOT, the HMIH-protected surface displays slightly more irregularities and localized attack sites, suggesting that its protective film is somewhat less uniform. This observation supports the electrochemical data where HMIH showed marginally lower Rt and inhibition efficiencies than KMPOT. The SEM findings complement the gravimetric (weight loss), potentiostatic, and EIS results by providing direct visual evidence of surface protection. While the blank sample confirmed severe corrosion damage, both inhibitors markedly suppressed surface deterioration, with KMPOT producing the most compact and uniform protective layer. These observations strongly support the conclusion that both inhibitors function through surface adsorption and barrier film formation, effectively isolating the steel surface from the corrosive medium.

4. CONCLUSION

This study successfully synthesized and evaluated two novel heterocyclic compounds, potassium(I) 5-(2-methylpyridin-4-yl)-1,3,4-oxadiazole-2-thiolate (KMPOT) and N′-(2-hydroxybenzylidene)-2-methylisonicotinohydrazide (HMIH), as corrosion inhibitors for mild steel in 1 N HCl solution. Comprehensive evaluation through gravimetric, electrochemical, and surface analyses confirmed their strong protective capabilities. Weight loss experiments showed that both inhibitors significantly reduced corrosion rates, with maximum inhibition efficiencies of 94.6% for KMPOT and 92.7% for HMIH at 500 ppm and 30 °C. Efficiency decreased at higher temperatures, suggesting predominantly physical adsorption, though strong surface interactions were maintained even at 100 °C (>80% efficiency). Potentiodynamic polarization studies revealed that both inhibitors act as mixed-type inhibitors with a predominant cathodic effect, suppressing both anodic dissolution and cathodic hydrogen evolution. Electrochemical impedance spectroscopy (EIS) confirmed a substantial increase in charge transfer resistance (Rt) and a reduction in double-layer capacitance (Cdl) with inhibitor addition, consistent with the formation of a protective adsorbed film that follows Langmuir adsorption behavior. Scanning electron microscopy (SEM) provided visual evidence of surface protection: the blank sample exhibited severe corrosion and pitting, whereas specimens treated with KMPOT and HMIH displayed smoother, less damaged surfaces. KMPOT offered a more compact and uniform protective layer compared to HMIH, consistent with its slightly higher inhibition efficiencies across all methods.

Overall, both inhibitors demonstrated excellent inhibition performance in aggressive acidic media, with KMPOT exhibiting marginally superior protective action due to stronger adsorption and film-forming ability. These results highlight the potential of KMPOT and HMIH as efficient, eco-friendly corrosion inhibitors suitable for industrial applications such as acid pickling, descaling, and pipeline cleaning.

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