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Data Article

Evaluation of the synergistic combination effect of four chemical compounds on the corrosion inhibition of carbon steel in dilute acid solutions

Roland Tolulope loto[a,*], Cleophas Akintoye Loto[a,b], Akanji Olaitan[b]

[a] *Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria*
[b] *Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Pretoria, South Africa*

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ABSTRACT

Synergistic combination of organic derivatives provide insight on alternative application of known chemical compounds for corrosion inhibition. The electrochemical corrosion inhibition of the combined admixture of vanillin and 1, 4-diaminobenzene (VDB), and vanillin with sodium molybdenum oxide (VSMO) on carbon steel in 1 M H_2SO_4 and HCl solutions was evaluated with weight loss measurement. Results show VDB performed more effectively in both acids with average inhibition efficiency above 85% in HCl and 90% in H_2SO_4 compared to VSMO whose average inhibition efficiency is slightly above 70% in HCl.

Specifications Table

Subject area	*Materials Engineering, Physical Sciences*
Compounds	*Sodium molybdenum oxide, vanillin, 1, 4-diaminobenzene, HCl and H_2SO_4*
Data category	*Coupon measurement*
Data acquisition format	*Weight measurement, analytic calculations*
Data type	*Filtered, analyzed,*
Procedure	*Carbon steels were immersed in 1 M HCl and H_2SO_4 solution at specific concentrations admixture of vanillin and 1, 4-diaminobenzene (VDB), and vanillin with sodium molybdenum oxide (VSMO). Inhibition efficiency was calculated from the difference in weight loss of the inhibited and control steel with respect to exposure time. Corrosion rate was calculated from weight loss measurement of inhibited and contro carbon steel specimens*
Data accessibility	*Data is with the article*

1. Rationale

Carbon steel is an important structural material worldwide, replacing cast iron as the most important ferrous alloy. The steel suffers from corrosion in aqueous environments containing SO_4^{2-} and Cl^- anions. Corrosion is responsible for a huge proportion of the overall expenditure of industries due to repair or replacement of badly corroded components, maintenance and corrosion control measures [1]. Acid anions are present in different industrial process environments such as pickling, descaling, acidizing, chemical processing, etc. causing accelerated deterioration of the steels present therein. Application of

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[*] Corresponding author.
E-mail address: tolu.loto@gmail.com (R. Tolulope loto).

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Table 1
Corrosion rate results of carbon steel in 1 M HCl/VDB (0 M–0.020 M) solution.

VDB Conc. (M)							
Exp. Time (h)	0	0.005 M	0.010 M	0.014 M	0.019 M	0.024 M	0.020 M
24	11.779	1.651	1.621	1.638	1.365	0.809	0.881
48	14.404	1.233	1.630	1.192	0.967	0.661	0.686
72	19.414	1.615	1.212	1.245	1.523	0.803	0.830
96	21.552	1.890	1.315	1.338	1.137	0.991	1.013
120	19.508	1.964	1.350	1.379	1.221	1.114	1.108
144	16.224	1.850	1.496	1.485	1.379	1.297	1.306
168	13.897	2.111	1.548	1.550	1.472	1.416	1.433

Table 2
Corrosion rate results of carbon steel in 1 M H_2SO_4/VDB (0 M–0.020 M) solution.

VDB Conc. (M)							
Exp. Time (h)	0	0.005 M	0.010 M	0.014 M	0.019 M	0.024 M	0.020 M
24	12.02	3.16	1.86	1.12	1.04	1.01	1.42
48	15.09	2.59	1.53	1.13	1.08	0.88	1.13
72	20.12	3.09	1.64	1.37	1.38	1.07	1.31
96	22.45	3.17	1.58	1.31	1.32	1.06	1.24
120	23.89	3.08	1.53	1.33	1.35	1.04	1.23
144	24.31	3.09	1.53	1.33	1.36	1.06	1.24
168	23.62	3.10	1.50	1.33	1.29	1.05	1.14

corrosion inhibitors significantly suppresses the degradation effect of corrosion reaction processes [2]. Chemical compounds of organic origin are the target of research experimentation directed towards the evolution and advancement of biodegradable corrosion inhibitor compounds [3–5]. Interference in the electrochemical processes responsible for corrosion has been the major goal of corrosion inhibitors for which suitable compounds have been discovered. However, research on the performance of these compounds can be improved through synergism with other compounds. Previous research on individual compound of 1, 4-diaminobenzene has shown it to highly concentration specific in corrosion inhibition performance which significantly limits its applicability [6,7]. The data reported in this article is on the synergistic combination effect of the combined admixture of vanillin and 1, 4-diaminobenzene (VDB), and vanillin with sodium molybdenum oxide (VSMO) on the inhibition of carbon steel corrosion in HCl and H_2SO_4 media.

2. Procedure

Cylindrical carbon steel rods (14 mm diameter) were machined into specific number of test specimens, each with average length of 10 mm. Each test specimen was carefully cleansed with distilled water and acetone for weight loss analysis. The chemical compounds, vanillin and 1, 4-diaminobenzene (VDB) were admixed in equal proportions (ratio 1:1) and prepared in molar concentrations of 0.005 M, 0.010 M, 0.014 M, 0.019 M, 0.024 M and 0.020 M respectively. Vanillin and sodium molybdenum oxide (VSMO) were also admixed in equal proportions and prepared in molar concentrations of 0.007 M, 0.014 M, 0.021 M, 0.028 M, 0.035 M and 0.042 M per 200 ml of 1 M H_2SO_4 and HCl acid media. Carbon steel specimens initially weighed were placed in 200 ml of the acid test solution at specific concentrations of VDB and VSMO separately. The steel specimens were taken out every 24 h and weighed with the total data recorded for a period of 168 h.

3. Data, value and validation

Weight loss data was obtained from the mathematical difference in weight between the first (initial) weight (the initial weight remains the same throughout) of the carbon steel specimen and every subsequent weight after measurement at 24 h interval. Tabulated results of corrosion rate (mm/y) (calculated) versus exposure time (h) for carbon steel in VDB/HCl solution, VDB/H_2SO_4 solution and VSMO/HCl solution are shown from Tables 1–3. Tables 4–6 shows the results of percentage inhibition efficiency (%*IE*) (calculated) versus exposure time in the same sequence for the carbon steel. The corrosion rate (*R*) from weight loss test was calculated from Eq. (1) below:

$$R = \left[\frac{87.6M}{\mathrm{DAT}}\right] \tag{1}$$

M is the weight loss in grams, *D* is the density in g/cm^2, *A* is the area in cm^2, and *T* is the time of exposure in hours. The %*IE* was determined from Eq. (2) below;

$$\%IE = \left[\frac{M_1 - M_2}{M_1}\right] * 100 \tag{2}$$

Table 3
Corrosion rate results of carbon steel from 1 M HCl/VSMO (0 M–0.042 M) solution.

VSMO Conc. (M)							
Exp. Time (h)	**0**	0.007 M	0.014 M	0.021 M	0.028 M	0.035 M	0.042 M
24	0.0075	0.0073	0.0031	0.0040	0.0053	0.0038	0.0045
48	0.0087	0.0068	0.0027	0.0042	0.0058	0.0039	0.0043
72	0.0116	0.0077	0.0040	0.0054	0.0052	0.0044	0.0047
96	0.0131	0.0077	0.0043	0.0056	0.0054	0.0044	0.0047
120	0.0147	0.0072	0.0039	0.0052	0.0050	0.0041	0.0044
144	0.0157	0.0069	0.0039	0.0049	0.0049	0.0041	0.0043
168	0.0169	0.0079	0.0046	0.0046	0.0045	0.0043	0.0046

Table 4
Inhibition efficiency results of VDB in 1 M HCl.

VDB Conc. (M)						
Exp. Time (h)	0.005 M	0.010 M	0.014 M	0.019 M	0.024 M	0.020 M
24	86.0	86.2	86.1	88.4	93.1	92.5
48	91.4	90.8	91.7	93.3	95.4	95.2
72	91.7	93.8	93.6	94.9	95.9	95.7
96	91.2	93.9	93.8	94.7	95.4	95.3
120	89.9	93.1	92.9	93.7	94.3	94.3
144	88.6	90.8	90.8	91.5	92.0	92.0
168	84.8	88.9	88.8	89.4	89.8	89.7

Table 5
Inhibition efficiency results of VDB in 1 M H_2SO_4.

VDB Conc. (M)						
Exp. Time (h)	0.005 M	0.010 M	0.014 M	0.019 M	0.024 M	0.020 M
24	73.7	84.5	90.6	91.3	91.6	88.2
48	82.8	89.9	92.5	92.8	94.2	92.5
72	84.6	91.9	93.2	93.2	94.7	93.5
96	85.9	93.0	93.9	94.1	95.3	94.5
120	87.1	93.6	94.5	94.4	95.6	94.9
144	87.3	93.7	94.5	94.4	95.6	94.9
168	86.9	93.6	94.4	94.6	95.5	95.2

Table 6
Inhibition efficiency results of VSMO in 1 M HCl.

VSMO Conc. (M)						
Exp. Time (h)	0.007 M	0.014 M	0.021 M	0.028 M	0.035 M	0.042 M
24	2.81	58.32	46.33	29.16	49.78	39.85
48	21.97	68.47	52.01	33.07	55.60	50.23
72	33.58	65.15	53.64	55.17	61.96	59.76
96	40.88	67.48	57.26	58.68	66.61	63.91
120	50.76	73.38	64.93	65.84	71.92	69.71
144	56.30	75.39	68.73	68.74	74.16	72.58
168	52.93	72.75	72.75	73.60	74.31	72.99

M_1 and M_2 are the corrosion rates in the presence and absence of specific VDB and VSMO inhibitor concentrations. The $\%IE$ was determined after every 24 h consecutively. Observation of Tables 1–3 shows the significant difference in the corrosion rate values between the inhibited carbon steels and the control specimens (without the inhibitor). Porous oxide (rust) formed on the control carbon steel due to the redox electrochemical processes occurring on the steel surface. These processes were enhanced by the presence of corrosive ions within the acid solution according to the following equations;

Anodic dissolution mechanism of carbon steel in the presence of Cl ions:

$$\mathrm{Fe} + \mathrm{Cl}\text{-} \rightarrow (\mathrm{FeCl}^-)_{\mathrm{ads}} \tag{3}$$

$$(\mathrm{FeCl}^-)_{\mathrm{ads}} \rightarrow (\mathrm{FeCl})_{\mathrm{ads}} + e^- \tag{4}$$

$$(\mathrm{FeCl})_{\mathrm{ads}} \rightarrow (\mathrm{Fe\ Cl}^+)_{\mathrm{ads}} + e^- \tag{5}$$

Cathodic hydrogen evolution mechanism is;

$$Fe + H^+ \rightarrow (FeH^+)_{ads} \tag{6}$$

$$(FeH^+)_{ads} + e^- \rightarrow (FeH)_{ads} \tag{7}$$

$$(FeH)_{ads} + H^+ + e^- \rightarrow Fe + H_2 \tag{8}$$

The significant decrease in corrosion rate upon addition of VDB and VSMO compounds results from the protonation of the inhibitor molecules in the acid media. The inhibitor molecules inhibit the redox electrochemical processes responsible for corrosion on the carbon steel surface. This behaviour is attributed to the effective surface coverage of the adsorbed inhibitor molecules on the steel surface. On Table 1, the corrosion rate continued to increase till 96 h before gradually decreasing till 168 h, while on Table 2, the corrosion rate increased continuously till 168 h. The phenomenon is due to the difference in oxidizing strength of H_2SO_4 compared to HCl. Nevertheless VDB performed effectively as shown from the corresponding inhibition efficiency values in Tables 4 and 5 where the average inhibition efficiency is above 80% from the onset of the corrosion test due to the concentration independent action of cationic VBD molecules in the acid solution. The extent to which VDB molecules chemisorbs on the carbon steel surface is subject to the presence and nature of heteroatoms within its molecular structure and the electron density on these atoms [8]. The inhibition efficiency values of VDB compound shows VDB molecules reduced the surface area of the carbon steel available for the attack of SO_4^{2-}or Cl^- ions. Previous research on this compound confirms this assertion as it was observed to display mixed type inhibition behaviour and the Gibbs free energy value depict chemisorption interaction [9]. Observation of the inhibition efficiency values exhibited by VSMO showed it narrowly scaled the 70% performance threshold; secondly, its performance is concentration and time dependent, which drastically reduces it performance index. The Fe^{2+}-VSMO complex formed on the carbon steel appears to be porous at low VSMO concentrations (0.007 M concentration) and there is the possibility that the formation of the protective film offered by VSMO occurred gradually with time leading to the poor corrosion rate values at the early onset of the exposure period [9,10]. At higher VSMO concentration, the molybdate component of VSMO strengthens the outermost hydrated iron oxide layer through H_2 bonding to OH^- groups on the carbon steel. Secondly, the presence of free electron pairs on the O_2 atom (reaction centre) forms coordination covalent bonds with Fe. i.e. the pi-electrons overlap with the vacant d-orbitals of the metal surface by displacing adsorbed water molecules according to the general equation [11–15]. These mechanisms results in a negative surface charge that inhibits the diffusion of SO_4^{2-} and Cl^- ions to the metal surface.

Conflict of interest

Authors declare no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cdc.2019.100210.

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