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Performance evaluation of the corrosion protection of admixture of *Cymbopogon nardus* and *Commiphora myrrha* on high carbon steel in CH_3COOH and $C_6H_8O_7$ solution

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ABSTRACT

Data from weight loss analysis on the protection performance of the combined admixture of *Cymbopogon nardus* and *Commiphora myrrha* (CCM) oil extracts on high carbon steel (HC-S) in 3 M CH_3COOH and $C_6H_8O_7$ acid solution was analysed. CCM extract performed effectively in CH_3COOH solution at minimum–maximum values of 53.06% and 80.12% at 168 h of exposure. These value corresponds with corrosion rate data of 1.238 mm/y and 0.525 mm/y relative to corrosion rate of HC-S (2.638 mm/y) at 0% CCM concentration. CCM performed poorly in $C_6H_8O_7$ solution with minimum–maximum values of 12.83% and 43.81% which corresponds to corrosion rates of 6.115 mm/y and 3.942 mm/y relative to corrosion rate value of 7.015 mm/y at 0% CCM concentration. The protection performance of CCM extract varies more significantly with respect to CCM concentration compared to measurement time. The statistical significance factor of CCM concentration in both acids are 64.85% and 93.93% compared to the corresponding values for measurement time at 25.95% and 4.11%. Standard deviation data for CCM extracts in CH_3COOH varied minimally from median values at 0.42% to 1.25% CCM concentration compared to the value at 1.67% CCM concentration. The standard deviation values for CCM in $C_6H_8O_7$ solution were relatively smaller than the values in CH_3COOH solution signifying greater thermodynamic stability. Data shows that 39.3% of CCM protection performance data in CH_3COOH is greater than 65% efficiency at margin of error of 18.1%. The corresponding value for CCM in $C_6H_8O_7$ solution is zero wherewith none of the protection performance data is greater than 65% protection efficiency.

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1. Introduction

Usage of carbon steels most industries results from their flexibility, adaptability, recyclability, ease of fabrication and adjustable engineering properties. Carbon steels applications occur in the form of structural beams, mechanical fixtures, pipes, supports, bolts and nuts etc. where rigidity is required. The mechanical characteristics of carbon steels are the basis upon which the properties of most metallic alloys are correlated [1]. One of the most important features associated with the versatility and high volume utilization of carbon steels compared to other steels is its low cost despite its relatively short lifespan. The operational lifespan of carbon steels is severely limited in the presence of corrosive anions in industrial environments. The lack of elements responsible for passivation in stainless steel ensures the continual degradation of the mechanical and physical properties of carbon steels oxidation of the steel [2,3]. Corrosion of carbon steels in service is responsible for industrial accidents, leakages, machine breakdown, collapse of structures etc. The consequential effects of these are huge maintenance and repair costs, pollution of the environment and expensive goods and services. Corrosion of carbon steels can be mitigated with the use of fluid derivatives identified as corrosion inhibitors. These compounds suppress the oxidation reactions leading to metallic corrosion by altering the electrochemical properties of the environment, forming a protective film of the metal surface

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and reaction with the corrosive anions to form a thermodynamically stable precipitate [4]. Traditional corrosion inhibitors are generally of inorganic origin, synthetic compounds and toxic organic chemicals [5–9]. Their utilization has endangered industrial personnel and environmental sustainability. Application of biodegradable compounds for corrosion inhibition has seen increasing use within the last decade due to the presence of phytochemical groups within their molecular structure. However, the wide variety of plant extracts available necessitates the need for caution and proper experimentation to ascertain their effectiveness. It is also worthy of note that some important phytochemical components require isolation. Other important factors that must be established are shelf life and strength of adsorption [10–14]. Essential oils extracts from plants, seeds, flowers, leaves, fruit skins etc. has been extensively researched into for evaluation of their protection performance properties, concentration for effective inhibition and the effect of measurement time on the performance variable of the extract [15–22]. In view of these, this manuscript studies the data output of the combined admixture of *Cymbopogon nardus* and *Commiphora myrrha* oil extracts on high carbon steel in dilute solutions CH_3COOH and $C_6H_8O_7$ acid. The admixed oil extracts have never been previously tested in the chosen acidic environments.

2. Experimental procedures

2.1. Materials and methods

Cymbopogon nardus and *Commiphora myrrha* oil extracts secured from NOW foods in USA (100% purity) were combined together in equal ratios into 3 M CH_3COOH and $C_6H_8O_7$ solution in proportions of 0.42%, 0.83%, 1.25% and 1.67%. High carbon steel rods designated as HC-S were separated into 5 test pieces for weight loss analysis. The 6 test pieces were cleansed with distilled H_2O and acetone prior to weight loss analysis. The HC-S test pieces were placed inside the acid/extract solution for 168 h of exposure. The weight of the test pieces was registered every 24 h interval with digital weighing instrument (resolution 0.0001 g, maximum capacity 110 g, repeatability 0.1 mg and linearity ± 0.2 mg). Weight loss was determined from the difference between the first weight of HC-S (kept for 168 h) and subsequent weight measured at 24 h interval. Corrosion rate of HC-S was estimated from equation (1) [23] below;

$$\mathbf{C_R} = \left[\frac{87.6\boldsymbol{W}}{\rho \mathbf{AT}}\right] \tag{1}$$

W denotes weight loss (g), ρ denotes density (g/cm^2), A denotes area (cm^2), and T symbolizes time of exposure (h). Inhibition efficiency (η) was enumerated from equation (2) [23].

$$\eta = \left[\frac{\boldsymbol{\omega}_1 - \boldsymbol{\omega}_2}{\boldsymbol{\omega}_1}\right] \times 100 \tag{2}$$

ω_1 denotes weight loss of HC-S from the acid solution without the extracts while ω_2 denotes weight loss of HC-S at precise extract concentration.

2.2. Statistical computation

Dual-factor analytical ANOVA test (F - test) was used to enumerate the statistical significance of CCM extract concentrations and measurement time on CCM protection efficiency results. The assessment was gotten at confidence level of 95% i.e. significance level of α = 0.05 in respect of the numerical expressions below. The combination of squares for the columns (measurement time) was enumerated from equation (3) [24].

$$\mathbf{SS_c} = \frac{\sum \mathbf{T_c}^2}{\mathbf{nr}} - \frac{\mathbf{T}^2}{\mathbf{N}} \tag{3}$$

The combination of squares between the rows (CCM extract concentration) was gotten from equation (4) [24].

$$\mathbf{SS_r} = \frac{\sum \mathbf{T_r}^2}{\mathbf{nc}} - \frac{\mathbf{T}^2}{\mathbf{N}} \tag{4}$$

The total combination of squares is given in equation (5) [24].

$$\mathbf{SS_{Total}} = \sum \mathbf{x}^2 - \frac{\mathbf{T}^2}{\mathbf{N}} \tag{5}$$

3. Results and discussion

3.1. Weight loss analysis

Corrosion resistance of HC-S in CH_3COOH and $C_6H_8O_7$ acid at specific CCM concentration was studied Table 1 depicts the corrosion rate data obtained while Table 2 shows the corresponding CCM inhibition efficiency in both acids. Observation of Table 1 shows significant variation between the corrosion rate data obtained from both acids. Secondly, the corrosion rate data in both acids without CCM oil extract is significantly higher than the data obtained in the presence of the extracts. The corrosion rate data from CH_3COOH acid decreased with respect to CCM concentration at 24 h of measurement from 0% and 1.25% CCM concentration (5.215 mm/y to 2.173 mm/y). At 1.67% CCM. corrosion rate slightly increased to 2.390 mm/y. Between 24 h and 168 h, observation shows corrosion rate data decreased at all CCM concentrations with final values varying between 2.638 mm/y (0% CCM), 1.238 mm/y (0.42% CCM) and 0.525 mm/y (1.67% CCM). Comparing these observations to HC-S corrosion rate data from $C_6H_8O_7$ acid; at 24 h, HC-S corrosion rate initiated with values of 12.167 mm/y at 0% CCM, 10.646 mm/y at 0.42% CCM till 8.256 mm/y at 1.67% CCM. Corrosion rate was also observed to decrease with increase in CCM concentration similar to its performance in CH_3COOH acid. Secondly, corrosion rate generally decreased with measurement time to values between 7.015 mm/y (0% CCM) and 3.942 mm/y (1.67% CCM) at 168 h of measurement. Nevertheless, the rate of corrosion is significantly higher in $C_6H_8O_7$ acid compared to CH_3COOH acid.

In both acids CCM proves to be a concentration dependent inhibitor whose protection performance improves with time. This assertion is further proven from the protection performance data in Table 2 where the protection efficiency of CCM in CH_3COOH initiated poorly at values below 60% (45.83% at 0.42% CCM concentration to 58.33% at 1.25% CCM concentration). Progressive in inhibition efficiency occurred at all concentrations till 168 h of measurement to values between 53.06% at 0.42% CCM concentration and 80.12% CCM concentration. In C6H8O7 acid, the protection performance data indicates poor inhibition effect by CCM inhibitor. The protection performance data initiated at values below 35% (24 h measurement time) and progressed to values generally below 45% at all CCM concentrations. The data shows values significantly below the threshold value for effective protection performance. Nevertheless, CCM inhibitor exhibited concentration dependent and time dependent inhibition action in $C_6H_8O_7$ acid on HC-S.

3.2. Statistical analysis

ANOVA statistical technique was applied to assess statistical significance of CCM oil extract concentration and measurement time on the protection performance of the CCM on HC-S. ANOVA statistical data is depicted in Table 3. The statistical significance

Table 1
Table 1 Data on HC-S corrosion rate from CH_3COOH and $C_6H_8O_7$ acid at specific CCM concentration.

CCM Conc. (%) Measurement Time (h)	CH_3COOH					$C_6H_8O_7$				
	0% CCM	0.42% CCM	0.83% CCM	1.25% CCM	1.67% CCM	0% CCM	0.42% CCM	0.83% CCM	1.25% CCM	1.67% CCM
24	5.215	2.825	2.347	2.173	2.390	12.167	10.646	9.777	9.126	8.256
48	3.476	1.847	1.412	1.391	1.369	10.103	8.691	7.713	7.061	6.301
72	3.187	1.506	1.231	0.992	0.927	9.198	7.822	6.808	6.084	5.359
96	2.933	1.407	1.135	0.918	0.760	8.148	7.007	6.247	5.866	5.052
120	2.868	1.330	1.073	0.869	0.643	7.605	6.649	5.780	5.388	4.606
144	2.716	1.293	1.043	0.829	0.558	7.170	6.301	5.577	5.142	4.273
168	2.638	1.238	0.984	0.801	0.525	7.015	6.115	5.370	4.811	3.942

Table 2
Data on CCM protection efficiency on HC-S in CH_3COOH and $C_6H_8O_7$ acid at specific CCM concentration.

CCM Conc. (%) Measurement Time (h)	CH_3COOH				$C_6H_8O_7$			
	0.42% CCM	0.83% CCM	1.25% CCM	1.67% CCM	0.42% CCM	0.83% CCM	1.25% CCM	1.67% CCM
24	45.83	55.00	58.33	54.17	12.50	19.64	25.00	32.14
48	46.88	59.38	60.00	60.63	13.98	23.66	30.11	37.63
72	52.73	61.36	68.86	70.91	14.96	25.98	33.86	41.73
96	52.04	61.30	68.70	74.07	14.00	23.33	28.00	38.00
120	53.64	62.58	69.70	77.58	12.57	24.00	29.14	39.43
144	52.40	61.60	69.47	79.47	12.12	22.22	28.28	40.40
168	53.06	62.71	69.65	80.12	12.83	23.45	31.42	43.81

Table 3
ANOVA data for CCM protection performance in H_2SO_4 CH_3COOH and $C_6H_8O_7$ solution.

Source of Variation	CH_3COOH			$C_6H_8O_7$		
	Mean Square Ratio (F)	Theoretical Significance Factor	Statistical Relevance Factor, F (%)	Mean Square Ratio (F)	Theoretical Significance Factor	Statistical Relevance Factor, F (%)
CCM Conc.	42.33	2.42	64.85	287.27	2.42	93.93
Measurement Time	8.47	2.10	25.95	6.28	2.10	4.11

factor shows the numerical influence of CCM concentration and measurement time on the protection performance of the CCM extracts. The theoretical significance factor represents the numerical value wherewith the mean square ratio must surpass, for the statistical significance factor to be significance. The mean square ratios for CCM extract concentrations and measurement time in CH_3COOH and $C_6H_8O_7$ acids are greater than the analogous theoretical significance factor. As a result, CCM concentration and measurement time are significant statistically. The statistical significance factor for CCM protection performance in CH_3COOH and $C_6H_8O_7$ at values of 64.85% and 93.03% substantially outweighs the corresponding values for measurement time in both acids (25.95% and 4.11%). This shows CCM concentration is the overwhelming determinant factor responsible for CCM extract protection performance. However, in CH_3COOH acid, the statistical relevance factor of 25.95% for measurement time still has substantial influence on the protection performance of CCM extract.

3.3. Standard deviation, mean and margin of error

Standard deviation (SD), mean and margin of error data obtained from the protection efficiency results of CCM extracts are presented in Table 4. The mean data depicts the median protection efficiency data in respect of CCM extract concentration. In CH_3COOH solution, the median data varies from 50.94% at 0.42% CCM to 70.99% at 1.67% CCM concentration. The corresponding values in $C_6H_8O_7$ solution varies from 13.28% at 0.42% CCM to 39.02% CCM concentration. SD data depict the degree of disparity of CCM protection efficiency from the median data. The degree of disparity of the protection efficiency from mean data gives information on the protective performance behavior of CCM extracts within the limits of measurement time and CCM concentration. SD data for CCM protection efficiency from 0.42% CCM to 1.25% CCM concentrations are relatively and significantly lower than the SD value at 1.67% CCM concentration. This shows the molecular interaction of protonated CCM molecules at 0.42% to 1.25% is relatively stable. At 1.67% CCM concentration, lateral interaction effect among the protonated extract molecules influences the inhibitor behavior in the acid solution and its interaction with HC-S surface during the redox reaction processes. This phenomenon occurs due to the presence of excess CCM molecules, and has the advantage of effectively suppressing the corrosion of the steel surface. The SD data from $C_6H_8O_7$ solution are significantly lower than the values obtained from CH_3COOH solution. The values varied from 1.04 at 0.42%

Table 4
Data for SD, mean, margin of error and data above 65% protection performance for CCM extracts in CH_3COOH and $C_6H_8O_7$ solution.

CH_3COOH Solution					$C_6H_8O_7$ Solution				
CCM Conc. (%)	0.42	0.83	1.25	1.67	**CCM Conc. (%)**	0.42	0.83	1.25	1.67
SD	3.19	2.69	4.97	9.99	**SD**	1.04	1.93	2.8	3.71
Mean	50.94	60.56	66.39	70.99	**Mean**	13.28	23.18	29.4	39.02
Margin of Error	18.10%	**Data above 65% Protection Eff.**		39.3%	**Margin of Error**	0%	**Data above 65% Protection Eff.**		0%

CCM to 3.71 at 1.67% CCM concentration. This show the protection behavior of CCM extract in $C_6H_8O_7$ solution is thermodynamically more stable than in CH_3COOH solution despite poor protection performance. The amount of data above 65% protection efficiency for CCM extracts in CH_3COOH solution is 39.3% at margin of error of 18.1%. The corresponding values for CCM in $C_6H_8O_7$ solution is zero.

4. Conclusion

Admixture of *Cymbopogon nardus* and *Commiphora myrrha* oil extracts effectively suppressed the corrosion of high carbon steel in CH_3COOH solution. Protection efficiency varied with increase in extract concentration achieving peak value of 80.12% at 1.67% extract concentration. This assertion contrasts the observation in $C_6H_8O_7$ solution where the extract performed poorly with protection efficiency generally below 50% at all extract concentrations studied. Disparity between the corrosion rate value of the protected and non-protected steel was significant in both acids. The protection performance of the extract was significantly influenced by variation in extract concentration and measurement time wherewith protection efficiency gradually increased.

CRediT authorship contribution statement

Roland Tolulope Loto: . **Edith Alagbe:** Conceptualization, Writing – review & editing.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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