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Data analysis of the corrosion protection behavior of ginger, tea tree and grapefruit essential oil extracts on low carbon steel in H_2SO_4 solution

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ABSTRACT

Application of corrosion inhibitors are the most versatile corrosion prevention methods of carbon steels in corrosive environments. Research on non-toxic chemical compounds are ongoing and results from previous study have proven the effectiveness of the compounds. Data on corrosion inhibition of ginger (GG), tea tree (TR) and grapefruit (GF) oil extracts on low carbon steel in 0.5 M H_2SO_4 are presented. The extracts performed effectively with optimal values of 99.56 %, 98.17 % and 98.32 % at 2.5 % GG, 3.5 % TR and 3 % GF concentrations. Corresponding corrosion rate values are 0.28 mm/y, 1.16 mm/y and 1.49 mm/y. Corrosion rate at 0 % extract concentration is 63.33 mm/y. Performance of TR extract significantly varies with time and concentration with statistical value of 48.21 % and 23.02 %. GG and GF concentration where the only statistically relevant factors for GG and GF performance with statistical values of 68.42 % and 73.20 %. Standard deviation data for GG extracts varied minimally from mean values compared to TR and GF extracts. Results shows 92 %, 18 % and 63 % of GG, TR and GF extracts inhibition data are above 95 % inhibition value at margin of error of 6.99 %, 10 % and 12.19 %.

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1. Introduction

Application of ferrous alloys cuts across most industries due to their versatility, ease of fabrication, recyclability and adaptable mechanical and physical properties. Ferrous alloys are used in structural columns and beams, components parts of industrial machines and critical components requiring toughness and hardness properties etc. The industrial properties of ferrous alloys serve as the conventional standards wherewith the properties of other metallic alloys of industrial importance are compared [1,2]. Coupled with this, the relatively low cost of ferrous alloys especially carbon steels substantially contribute to the high volume utilization of ferrous alloys. Carbon steels, despite their universal industrial application compared to other metallic alloys are prone to rapid deterioration in aqueous condition containing appreciable concentrations of Cl^-, SO_4^{2-}, $S_2O_3^{2-}$, NO_3- etc. due to the absence of passivating elements within their metallurgical structure [3]. As a result, redox electrochemical processes occurs on the heterogeneous alloy surface [4]. Invariably, the operating lifespan of the steel is severely shortened leading to plant shutdown, industrial downtime, failure of mechanical parts/components, excessive maintenance and repair cost, and industrial accidents. Chemical compounds known as corrosion inhibitors stifles the electrochemical reactions responsible for carbon steel corrosion when added to the steel's operating environment. Other actions of corrosion inhibitors include formation non-reactive chemical precipitates, adsorption unto the steel surface and alteration of the corrosive properties of the electrolyte [5]. Proven corrosion inhibitor e.g. chromates, nitrites, aniline etc. such as are toxic and unsustainable [6–10]. Plant extracts are promising corrosion due to their phytochemical components though experimental data show extensive investigation is necessary to further establish their corrosion inhibition properties, isolation of active components, extension of their shelf life and improved adsorption properties [11–15]. Essential oils extracts from plants, leaves, fruits and seeds have been investigated to assess their protection performance potentials and to delineate their highest corrosion inhibition output with respect of exposure time and extract concentration [16–23]. This article computes and analyses the data outputs and statistical importance of the inhibition efficiency data for ginger, tea tree and

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grapefruit essential oil extracts on low carbon steel in 0.5 M H_2SO_4 solution.

2. Experimental methods

2.1. Materials and methods

Ginger (GG), tea tree (TR) and grapefruit oil extracts purchased from NOW foods USA at 100 % purity were added individually to 0.5 M H_2SO_4 solution in volumetric concentrations of 1 %, 1.5 %, 2 %, 2.5 %, 3 % and 3.5 %. Low carbon steel (LCS) rods were cut into six separate samples for weight loss measurement. The 6 samples were washed with deionized H_2O and propanone before weight loss test. The LCS samples were inserted into each acid/extract solution (with respect to inhibitor concentration) contained in 6 separate glass beakers for 240 h after initial measurement. Weight of the specimens were recorded at 24 h interval with Ohaus PA114 measuring device with resolution of 0.0001 g, maximum capacity is 110 g, repeatability is 0.1 mg and linearity is ± 0.2 mg. Weight loss was determined from the subtraction between the initial weight of LCS (maintained for 240 h) and subsequent weight measured at 24 h interval for a total of 240 h. Corrosion rate of LCS was determined from the equation below;

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

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 the following equation;

$$\eta = \left[\frac{\omega_1 - \omega_2}{\omega_1}\right] \times 100 \tag{2}$$

ω_1 denotes weight loss of LCS from the acid solution without the distillates while ω_2 denotes weight loss of LCS at precise extract concentration.

2.2. Statistical computation

Dual-factor empirical ANOVA test (F - test) was applied to compute the statistical relevance of extract concentrations and exposure time on GG, TR and GF inhibition efficiency data. The evaluation was realized at confidence level of 95 % i.e. a significance level of α = 0.05 in accordance with the equations below. The aggregate of squares of columns (exposure time) was enumerated as shown;

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

The aggregate of squares between rows (oil extract concentration) was enumerated from equation (4)

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

Total aggregation of squares

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

3. Results and discussion

3.1. Coupon analysis

Experimental data for LCS corrosion rate in the presence of GG, TR and GF essential oil extracts, and extract inhibition efficiency in H_2SO_4 solution are presented in Table 1. Corrosion rate data for LCS at 0 % extract concentration is substantially greater than the values obtained at 1 % to 3.5 % GG, TR and GF extract concentration. The is due to the accelerated degradation of LCS occurring from the redox electrochemical mechanisms. At 0 % extract concentration, corrosion rate initiated at 41.95 mm/y (24 h), attained peak value at 144 h (79.30 mm/y) before decreasing to 63.33 mm/y at 240 h whereas, addition of the extracts significantly reduced the corrosion of LCS in H_2SO_4 solution. GG extract generally displayed the lowest corrosion rate values compared to TR and GF extracts at all concentrations studied. GG extract values initiated at 0.84 mm/y to 0.84 mm/y (1 % GG to 3.5 % GG) at 24 h, though significant variation of corrosion rate values occurred from 1.5 % to 3 % GG concentration. Corrosion rate of LCS generally decreased with exposure time at all GG concentration from 24 h to 240 h of exposure but varies non-linearly with respect to GG concentration. The decrease is due to the effective protection performance of GG molecules in counteracting the electrochemical processes induced by SO_4^{2-} ions. At 1 % GG concentration corrosion rate increased from 0.84 mm/y at 24 h to 5.01 mm/y at 240 h. This is as a result of the inability of insufficient protonated molecules of GG extract hinder the corrosive reaction processes.

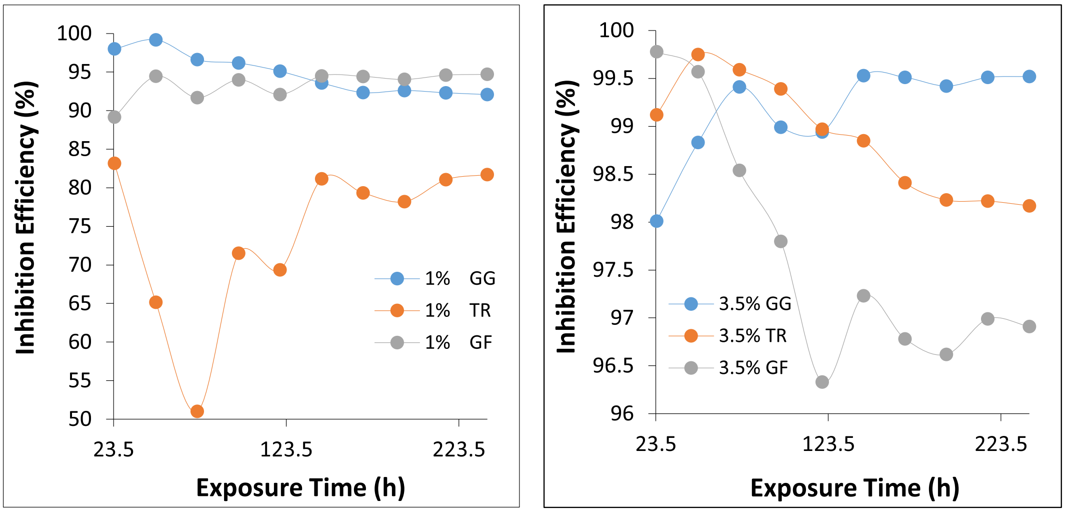
The effective performance of GG extract is followed by the performance of GF extract, while TR extract performance was relatively the least effective compared to GG and GF extracts. At 24 h LCS corrosion rate varied in non-linearly with respect to TR concentration. The lowest corrosion rate of 0.37 mm/y occurred at 3.5 % TR concentration. At 240 h, it is obvious that the corrosion rate of LCS decreases with increase in TR extract concentration and exposure time. The corrosion rate values vary from 11.58 mm/y at 1 % TR concentration to 1.16 mm/y at 3.5 % TR concentration. At 24 h, GF extract vary between 4.55 mm/y (1 % GF concentration) and 0.09 mm/y (3.5 % GF concentration) while at 240 h, the values varies between 3.35 mm/y and 1.96 mm/y. Observation shows corrosion rate of LCS increases with exposure time at all GF concentrations but varies non-linearly with respect to GF concentration. Further observation of the protection performance of GG, TR and GF extracts are depicted by the inhibition efficiency data in Fig. 1Table 1. Inhibition efficiency trend for the extracts aligns with the trend observed in corrosion rate values. Beyond 1 % GG concentration, GG inhibition efficiency values at 240 h were generally constant signifying stability of the protective film of GG extract on LCS. The corresponding inhibition efficiency values for TR extracts increased with increase in extract concentration at 240 h from 81.71 % to 98.17 %, signifying extract concentration dependent performance. Inhibition efficiency of GF extract varied from 94.71 % to 96.91 % at 240 h in a non-linear manner.

3.2. Statistical analysis

ANOVA statistical method was used to evaluate the statistical importance of GG, TR and GF extract concentration and exposure time on the protection performance of the extracts on LCS. Data from ANOVA analysis is shown in Table 3. Statistical relevance factor represents the percentage value of the effects of extract concentration and exposure time on the protection performance of the extracts. Theoretical significance factor represents the value at which the mean square ratio must be greater than, for the statistical relevance factor to be relevant. The mean square ratios for GG and GF extract concentrations are greater than the corresponding theoretical significance factor; hence they are statistically relevant and significantly influences the electrochemical action of the extracts at percentage value of 68.42 % and 73.20 %. Their corresponding values for mean square ratio for exposure time are substantially lower than the theoretical significance factor indicating that they have no effect on the performance of the extracts. The corresponding statistical relevance factors at 2.58 % and 4.40 %

Table 1
Experimental data for LCS corrosion rate GG/H_2SO_4, TR/H_2SO_4 and GF/H_2SO_4, and GG, TR and GF extract inhibition efficiency.

GG Extract	**Corrosion Rate (mm/y)**							**Inhibition Efficiency (%)**					
GG Conc.(%) Exp. Time (h)	**0 % GG**	**1 % GG**	**1.5 % GG**	**2 % GG**	**2.5 % GG**	**3 % GG**	**3.5 % GG**	**1 % GG**	**1.5 % GG**	**2 % GG**	**2.5 % GG**	**3 % GG**	**3.5 % GG**
24	41.95	0.84	0.56	1.30	0.19	1.39	0.84	98.01	98.67	96.90	99.56	96.68	98.01
48	75.36	0.60	0.42	0.88	0.14	1.11	0.88	99.20	99.45	98.83	99.82	98.52	98.83
72	52.87	1.79	0.12	0.56	0.34	0.59	0.31	96.61	99.77	98.95	99.36	98.89	99.41
96	68.59	2.62	0.32	0.58	0.49	0.65	0.70	96.18	99.53	99.15	99.29	99.05	98.99
120	56.13	2.75	0.28	0.59	0.48	0.63	0.59	95.11	99.50	98.94	99.14	98.88	98.94
144	79.30	5.07	0.20	0.48	0.42	0.54	0.37	93.60	99.75	99.40	99.47	99.32	99.53
168	70.04	5.36	0.28	0.52	0.42	0.46	0.34	92.35	99.60	99.26	99.39	99.34	99.51
192	63.52	4.69	0.24	0.45	0.37	0.46	0.37	92.62	99.62	99.29	99.42	99.27	99.42
216	66.98	5.15	0.31	0.38	0.36	0.41	0.33	92.32	99.54	99.43	99.46	99.38	99.51
240	63.33	5.01	0.34	0.35	0.28	0.38	0.31	92.09	99.46	99.44	99.56	99.40	99.52
TR Extract	**Corrosion Rate (mm/y)**							**Inhibition Efficiency (%)**					
TR Conc.(%)	**0.0 % TR**	**1 % TR**	**1.5 % TR**	**2 % TR**	**2.5 % TR**	**3 % TR**	**3.5 % TR**	**1 % TR**	**1.5 % TR**	**2 % TR**	**2.5 % TR**	**3 % TR**	**3.5 % TR**
Exp. Time (h)													
24	41.95	7.05	12.62	0.93	11.51	3.71	0.37	83.19	69.91	97.79	72.57	91.15	99.12
48	75.36	26.26	38.14	5.81	9.00	10.07	0.19	65.15	49.38	92.28	88.05	86.64	99.75
72	52.87	25.89	41.36	10.09	10.64	18.93	0.22	51.02	21.77	80.92	79.87	64.19	99.59
96	68.59	19.54	19.51	15.08	10.65	13.97	0.42	71.52	71.55	78.01	84.47	79.63	99.39
120	56.13	17.21	16.98	12.60	10.04	11.34	0.58	69.35	69.74	77.55	82.11	79.79	98.97
144	79.30	14.94	14.35	11.26	8.71	9.50	0.91	81.16	81.90	85.81	89.02	88.02	98.85
168	70.04	14.48	13.18	9.97	8.64	8.43	1.11	79.33	81.18	85.76	87.66	87.96	98.41
192	63.52	13.85	11.91	8.89	7.78	7.39	1.13	78.19	81.24	86.00	87.74	88.37	98.23
216	66.98	12.69	10.78	7.92	7.22	6.76	1.19	81.05	83.91	88.18	89.22	89.90	98.22
240	63.33	11.58	10.14	7.23	6.57	6.22	1.16	81.71	83.98	88.58	89.62	90.17	98.17
GF Extract	**Corrosion Rate (mm/y)**							**Inhibition Efficiency (%)**					
GF Conc.(%)	**0 % GF**	**1 % GF**	**1.5 % GF**	**2 % GF**	**2.5 % GF**	**3 % GF**	**3.5 % GF**	**1 % GF**	**1.5 % GF**	**2 % GF**	**2.5 % GF**	**3 % GF**	**3.5 % GF**
Exp. Time (h)													
24	41.95	4.55	6.59	2.51	0.84	0.93	0.09	89.16	84.29	94.03	98.01	97.79	99.78
48	75.36	4.18	32.07	2.65	1.30	1.21	0.32	94.46	57.45	96.49	98.28	98.40	99.57
72	52.87	4.39	31.12	2.60	1.21	1.27	0.77	91.69	41.14	95.08	97.72	97.60	98.54
96	68.59	4.11	23.69	2.55	1.32	1.21	1.51	94.01	65.46	96.28	98.07	98.24	97.80
120	56.13	4.44	19.04	2.84	1.54	1.23	2.06	92.10	66.07	94.94	97.26	97.82	96.33
144	79.30	4.35	16.38	2.92	1.62	1.25	2.20	94.52	79.34	96.31	97.95	98.42	97.23
168	70.04	3.88	14.25	2.89	1.50	1.27	2.25	94.45	79.65	95.87	97.86	98.18	96.78
192	63.52	3.78	12.61	2.87	1.67	1.23	2.15	94.05	80.15	95.49	97.37	98.06	96.62
216	66.98	3.61	11.32	2.76	1.57	1.17	2.02	94.61	83.09	95.87	97.66	98.26	96.99
240	63.33	3.35	10.28	3.13	1.49	1.06	1.96	94.71	83.77	95.06	97.65	98.32	96.91



(a) (b)

Fig. 1. Comparative plots for GG, TR and GF inhibition efficiency data at (a) 1% extract concentration and (b) 3.5% extract concentration.

confirms this assertion. The mean square ratio for TR extract concentration and exposure time are greater than the corresponding theoretical significance factor. Hence, they are statistically relevant at percentage values of 48.21 % and 23.02 %.

3.3. Standard deviation, mean and margin of error

Data on standard deviation (SD), mean and margin of error for the inhibition efficiency data of GG, TR and GF extracts are shown

Table 2
Data for SD, mean, margin of error and proportion above 95% inhibition performance for GG, TR and GF extracts in H_2SO_4 solution.

GG Extract						
GG Conc. (%)	1	1.5	2	2.5	3	3.5
SD	2.6	0.31	0.76	0.18	0.82	0.49
Mean	94.81	99.49	98.96	99.45	98.87	99.17
Margin of Error	6.99 %	**Proportion of Data above 95 % Inhibition Efficiency**		92 %		
TR Extract						
TR Conc. (%)	1	1.5	2	2.5	3	3.5
SD	10.14	19.81	6.24	5.46	8.22	0.59
Mean	74.17	69.46	86.09	85.03	84.58	98.87
Margin of Error	10 %	**Proportion of Data above 95 % Inhibition Efficiency**		18 %		
GF Extract						
GF Conc. (%)	1	1.5	2	2.5	3	3.5
SD	1.83	14.27	0.77	0.32	0.28	1.24
Mean	93.38	72.04	95.54	97.78	98.11	97.66
Margin of Error	12.19 %	**Proportion of Data above 95 % Inhibition Efficiency**		63 %		

Table 3
ANOVA data for GG, TR and GF inhibition performance in H_2SO_4 solution.

GG Extract			
Source of Variation	**Mean Square Ratio (F)**	**Theoretical Significance Factor**	**Statistical Relevance Factor, F (%)**
Extract Conc.	21.23	2.42	68.42
Exposure Time	0.44	2.10	2.58
TR Extract			
Source of Variation	**Mean Square Ratio (F)**	**Theoretical Significance Factor**	**Statistical Relevance Factor, F (%)**
Extract Conc.	15.08	2.42	48.21
Exp. Time	4.00	2.10	23.02
GF Extract			
Source of Variation	**Mean Square Ratio (F)**	**Theoretical Significance Factor**	**Statistical Relevance Factor, F (%)**
Extract Conc.	29.40	2.42	73.20
Exp. Time	0.98	2.10	4.40

in Table 2. The mean data shows the average inhibition efficiency values with respect to extract concentration. The SD values shows the amount of variation of extract inhibition efficiency from the mean value. The extent of variation of extracts inhibition efficiency from mean value provides insight on the stability of the protective performance of the extracts with respect to time and extract concentration. SD values for GG extracts at all GG concentrations are comparatively the lowest compared to TR and GF extracts due to stability of GG molecules over LCS surface in H_2SO_4. It shows the protection performance of GG extract vary minimally with respect to exposure time and concentration. Lateral interaction effect was quite negligible and the molecules effectively protected the steel. The SD values for TR inhibition efficiency data are relatively the highest which shows the molecular interaction of TR molecules over LCS surface varies significantly with exposure time and concentration. It shows time variation significantly influences the stability and protective performance of the extract. The proportion of data above 95 % inhibition efficiency for the GG, TR and GF extracts are 92 %, 18 % and 63 % at margin of error of 6.99 %, 74.17 % and 12.19 %.

4. Conclusion

Ginger, tea tree and grapefruit oil extracts effectively inhibited low carbon steel corrosion with optimal values generally greater than 98 %. Variation in corrosion rate between the inhibited and non-inhibited steel varies significantly due to effective protection mechanisms of the extract on the carbon steel in acid solution. Results also showed measurement time and concentration significantly influenced the performance of tea tree extract i.e. performance increases with time and concentration. However, extract concentration was the only relevant non-dependent variable responsible for the protection performance of ginger and grapefruit extracts.

CRediT authorship contribution statement

Roland Tolulope Loto: Supervision, Conceptualization, Writing – original draft, Visualization, Investigation, Validation, Methodology, Data curation. **Edith Alagbe:** . **Ayobami Busari:** .

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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