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Data on the corrosion inhibition effect of non-toxic organic derivatives on high carbon steel in dilute acid media

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ABSTRACT

The toxicity of prevalent organic and inorganic corrosion inhibitors necessitates the search for biodegradable corrosion inhibitors. Data on the inhibition effect of biodegradable L-leucine (LLC) in 1 M HCl and L-leucine in combination with trypsin complex (LLCT) in 1 M H₂SO₄ on the corrosion inhibition of high carbon steel was evaluated with coupon analysis. Results from the analysis shows LLC and LLCT were highly effective with maximum inhibition efficiency of 85.88% and 90.08%. Thermodynamic calculations showed chemisorption molecular interaction and adsorption onto HCS surface for the inhibitor compounds in the acid media.

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Specifications Table

Subject area	Materials Engineering, Physical Sciences
Compounds	L-leucine, trypsin, HCl, H ₂ SO ₄
Data category	Coupon measurement
Data acquisition format	Weight measurement, analytic calculations
Data type	Filtered, analyzed,
Procedure	High carbon steels were immersed in 1 M HCl and H ₂ SO ₄ solution at specific concentrations of L-leucine and L-leucine in combination with trypsin complex. Inhibition efficiency was calculated from the difference in weight loss of the inhibited and control steel with respect to exposure time
Data accessibility	Data is with the article

1. Rationale

Carbon steel is the most applicable engineering material, accounting for about 85% of the total annual global steel production and is the largest single classification of metallic alloys applied in tonnage and total cost [1]. Carbon steel has extensive application in marine, petrochemical, refining, chemical processing, mining, construction, metal-processing and power plants generating industries. They are extensively applied in industry as materials of construction for equipment, machines, devices and plants structures [2]. Most industrial environments are highly corrosive to these alloys during application. HCl and H₂SO₄ have significant application as intermediate chemicals in the production of detergents, synthetic

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Table 1
Percentage Nominal Composition of HCS.

Element symbol	Mn	P	S	C	Fe
% Composition	0.5	0.04	0.05	0.90	98.51

resins, dyestuffs, pharmaceuticals, petroleum catalysts, insecticides and antifreeze etc. Some other processes such as paper sizing, water treatment, oil well acidizing, aluminium reduction, removal of scales from metallic surfaces also use these acids [3–6]. The dilute electrolytic phase in the overhead condenser of crude distillation units resulting from dissolved NaCl solution during refining of crude oil contains significant HCl acid which is released by the hydrolysis of CaCl_2 and MgCl_2 [7–10]. The presence of HCl is responsible for corrosion of the metallic components of the distillation unit. Corrosion in this unit is mostly due to condensed HCl acid. Corrosion problems are associated with material degradation leading to process interruptions and plant shutdown. The damage results from electrochemical interaction of metallic surfaces with their environment [11]. The problem with carbon steel is that the oxide formed by oxidation does not firmly adhere to the surface of the metal and flakes off easily causing catastrophic general surface deterioration [12,13]. There are cases where corrosion damage is tolerable but eventually leads higher maintenance costs with minimal loss. The low corrosion resistance of high carbon steel limits their sustainable application [14]. Application of specific chemical compounds known as corrosion inhibitors has been proven to be the most practical technique of corrosion control of metal degradation [15–17]. Inhibitors of organic origin are considered to be effective corrosion inhibitors. However, the toxic nature and relatively high cost of organic inhibitors necessitates the need for sustainable alternatives. Use of low-cost and eco-friendly compounds as corrosion inhibitors have gradually replaced their toxic counterparts in recent years leading to research for more effective corrosion inhibiting derivatives [18–26]. The data reported in this article focusses on the corrosion inhibition performance of leucine and the combined admixture of leucine with trypsin complex.

2. Procedure

High carbon steel (HCS) has a nominal (wt.%) composition shown in Table 1. The steel specimen were abraded with silicon carbide papers (80, 320, 600, 800 and 1000 grit) after machining, before cleansing with deionized water and acetone, and kept in a desiccator for coupon analysis. Seven containers of 200 mL of 1 M HCl was prepared with volumetric concentrations of 0%, 1%, 2%, 3%, 4%, 5% and 6% LLC was prepared from analar grade of HCl acid (37%) with deionized water. The same process was repeated for 1 M H_2SO_4 with volumetric concentrations of 0%, 1%, 2%, 3%, 4% and 5% LLCT prepared from analar grade (98%). HCS coupons separately immersed in 200 mL of the dilute acid test solution for 288 h at 30 °C were weighed at 24 h interval using Ohaus weighing balance. The weighing balance was checked for possible causes of systematic errors. The uncertainty of single measurement is limited by the precision and accuracy of the measuring instrument. As a result calibration of the instrument and hardware test was performed. Inhibition efficiency (η) was determined from the equation below;

$$\eta = \left[\frac{\tilde{\omega}_1 - \tilde{\omega}_2}{\tilde{\omega}_1} \right] \times 100 \quad (1)$$

ω_1 and ω_2 are the mass loss at specific inhibitor concentrations. Surface coverage was gotten from the relationship:

$$\theta = \left[1 - \frac{\omega_2}{\omega_1} \right] \quad (2)$$

where θ is the degree of inhibitor compound adsorbed per gram on HCS surface.

3. Data, value and validation

Tables 2 and 3 show the weight loss data for HCS in HCl/LLC and H_2SO_4 /LLCT solution. The weight loss was obtained from the mathematical difference in weight between the first-initial weight (the initial weight remains the same throughout) and every subsequent weight after measurement at 24 h interval. The weight loss of HCS in the control solution (0% LLC and LLCT) in both acid-inhibitor solution was significantly higher than the data obtained in the presence of the inhibitors. This is due to the surface oxidation of HCS leading to accelerated electrochemical deterioration. The rate of deterioration was much higher in H_2SO_4 than in HCl due to the higher ionization potential of H_2SO_4 in H_2O . In the presence of the inhibiting compounds, the weight loss values decreased sharply due to the suppression of the redox electrochemical processes responsible for corrosion. Tables 4 and 5 shows the data for inhibition efficiency of LLC and LLCT. The inhibition efficiency values were calculated from the formula in Eq. (1). LLCT performed slightly higher than LLC due to the synergistic effect of two different compounds. Observation of Tables 4 shows a progressive increase in inhibition efficiency indication that LLC performance is strongly dependent on exposure time. However, Table 5 shows a sharp increase in inhibition efficiency from the 72 h of the exposure hours before gradually progressing upwards till 288 h.

Table 2Corrosion rate data for HCS corrosion in 1 M HCl/LLC (0–6% conc.) solution ($n = 1$).

Exp. time (h)	LCC conc. (%)						
	0% LCC	1% LCC	2% LCC	3% LCC	4% LCC	5% LCC	6% LCC
24	0.010	0.009	0.009	0.006	0.007	0.007	0.005
48	0.009	0.006	0.007	0.005	0.005	0.005	0.004
72	0.008	0.005	0.005	0.003	0.004	0.004	0.003
96	0.009	0.004	0.005	0.003	0.003	0.003	0.003
120	0.009	0.004	0.004	0.003	0.003	0.003	0.002
144	0.010	0.004	0.004	0.003	0.003	0.002	0.002
168	0.010	0.004	0.004	0.002	0.002	0.002	0.002
192	0.010	0.004	0.004	0.002	0.002	0.002	0.002
216	0.011	0.003	0.003	0.002	0.002	0.002	0.002
240	0.011	0.003	0.003	0.002	0.002	0.002	0.002
264	0.011	0.003	0.003	0.002	0.002	0.002	0.002
288	0.011	0.003	0.003	0.002	0.002	0.002	0.002

Table 3Corrosion rate data for HCS corrosion in 1 M H₂SO₄/LLCT (0–5% conc.) solution ($n = 1$).

Exp. time (h)	LCCT conc. (%)					
	0% LCCT	1% LCCT	2% LCCT	3% LCCT	4% LCCT	5% LCCT
24	0.012	0.010	0.009	0.008	0.009	0.008
48	0.012	0.007	0.006	0.005	0.006	0.006
72	0.013	0.006	0.004	0.004	0.004	0.004
96	0.012	0.005	0.004	0.003	0.003	0.003
120	0.013	0.005	0.003	0.003	0.003	0.003
144	0.012	0.004	0.003	0.002	0.002	0.002
168	0.012	0.004	0.003	0.002	0.002	0.002
192	0.012	0.004	0.002	0.002	0.002	0.002
216	0.011	0.004	0.002	0.002	0.002	0.002
240	0.011	0.003	0.002	0.002	0.002	0.002
264	0.012	0.003	0.002	0.002	0.002	0.002
288	0.012	0.003	0.002	0.001	0.002	0.002

Table 4Inhibition efficiency data for HCS corrosion in 1 M HCl/LLC (0–5.6% conc.) solution ($n = 1$).

Exp. time (h)	LCC conc. (%)					
	1% LCC	2% LCC	3% LCC	4% LCC	5% LCC	6% LCC
24	12.43	14.04	41.52	34.77	30.93	51.19
48	27.36	25.87	47.39	44.19	46.30	55.24
72	37.42	35.58	61.77	52.78	54.56	60.71
96	48.98	46.17	65.62	63.21	65.40	69.38
120	55.51	53.24	71.33	69.52	71.94	74.06
144	60.56	58.41	75.71	74.60	77.02	78.08
168	62.92	62.11	77.39	76.48	79.03	79.90
192	64.92	65.59	79.16	78.48	80.84	81.72
216	67.73	68.83	80.55	80.03	82.39	83.16
240	69.58	70.81	81.45	81.01	83.36	84.15
264	71.19	73.25	82.14	82.16	84.19	85.01
288	72.35	75.10	82.82	83.09	85.02	85.88

Fig. 1(a) shows the plot Gibbs free energy versus LLC concentration, while Fig. 1(b) shows the plot of Gibbs free energy versus LLCT concentration. Gibbs free energy was determined from the equation below

$$\Delta G_{\text{ads}} = -2.303RT \log[55.5K_{\text{ads}}] \quad (3)$$

where 55.5 is the molar concentration of water in the acid solution, R is the universal gas constant, T is the absolute temperature and K_{ads} is the equilibrium constant of adsorption determined from the Langmuir equation below;

$$\theta = \left[\frac{K_{\text{LCN}}C_{\text{LCN}}}{1 + K_{\text{ads}}C_{\text{LCN}}} \right] \quad (4)$$

θ is the amount of inhibitor adsorbed per unit gram on HCS surface at equilibrium. C is inhibitor concentration. Data on Gibbs free energy shows the strength of adsorption of the inhibitor molecules on HCS. According to the plots [Fig. 1(a) and (b)], increase in inhibitor concentration is proportional to decrease in Gibbs free energy value. However, the values in

Table 5

Inhibition efficiency data for HCS corrosion in 1 M H₂SO₄/LLCT (0%–5% conc.) solution ($n = 1$).

Exp. time (h)	LCCT conc. (%)				
	1% LCCT	2% LCCT	3% LCCT	4% LCCT	5% LCCT
24	17.49	31.00	35.10	23.86	36.55
48	38.03	50.49	56.18	50.19	53.85
72	56.74	66.96	72.73	68.40	69.35
96	59.71	70.27	75.54	73.11	73.13
120	64.05	75.61	80.08	78.38	79.47
144	66.11	76.37	83.06	80.31	80.82
168	66.32	77.41	82.84	81.43	81.99
192	67.69	78.55	83.62	82.43	82.96
216	67.51	78.09	83.86	82.77	83.36
240	70.35	80.15	85.42	84.55	85.06
264	73.04	81.94	86.95	86.13	86.52
288	74.75	83.21	87.93	87.16	87.42

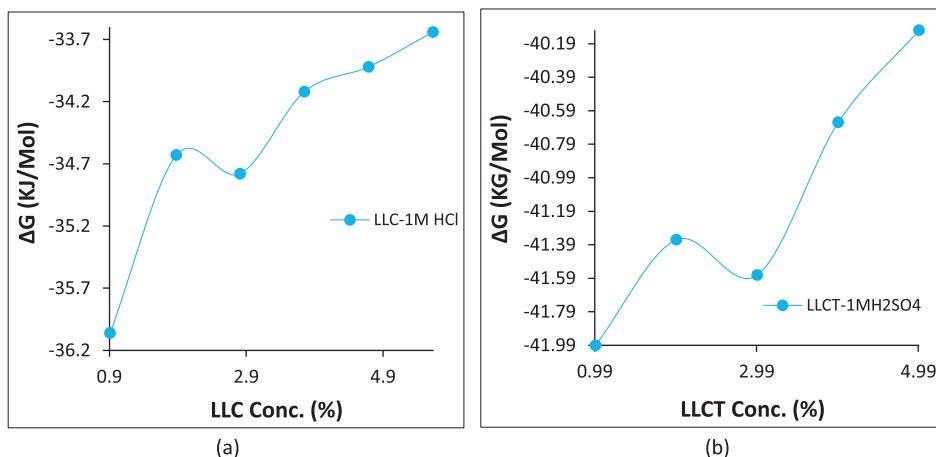


Fig. 1. Plot of Gibbs free energy versus exposure time for HCS inhibition in (a) 1 M HCl/LLC inhibitor, and (b) 1 M H₂SO₄/LLCT.

Fig. 1(a) are quite lower than values in **Fig. 1(b)**. Observation of the data shows the adsorption mechanism for LLC on HCS is physiochemical while the adsorption for LLCT on HCS in chemisorption i.e. stronger electrochemical interaction leading to a protected HCS surface.

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Conflict of interest

Authors declare no conflict of interest.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:[10.1016/j.cdc.2019.100214](https://doi.org/10.1016/j.cdc.2019.100214).

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