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Corrosion Inhibitor Potential of Tropical Milkweed (*Asclepias Curassavica*) Plant Leaf Extracts for Reinforced Bars in Chloride Concentrated Environment

*¹UGI, BU; ²OJI, NN; ³UGI, FB; ⁴UGI, DU; ³TAMUNOTONYE, GT

^{*1}Department of Pure & Industrial Chemistry, University of Calabar, P.M.B. 1115 Calabar, Nigeria

²Department of Science Laboratory Technology, Federal Polytechnic Ugep, Cross River State, Nigeria

³Department of Chemical / Petrochemical Engineering, Rivers State University, Port Harcourt, Rivers State, Nigeria

⁴Department of Test, Measurement and Evaluation, Joseph Sarwan Tarkar University (University of Agriculture) Makurdi, Benue State, Nigeria

*Correspondence author: ugibenedict@gmail.com

*ORCID: <https://orcid.org/0000-0003-0697-8280>

*Tel: +2347067921098

Co-Authors Emails: Ojonse490@gmail.com; fredrick.ugi@rsu.edu.ng; donugi123@gmail.com; tamunotonye.tamunu-nemgiofon@ust.eu.ng

ABSTRACT: The objective of this paper was to evaluate the corrosion inhibitor potential of tropical milkweed (*Asclepias Curassavica*) plant leaf extracts for reinforced bars in chloride concentrated environment using the conventional mass loss method, electrochemical impedance spectroscopic method and potentiodynamic polarization method. The nature of adsorption was considered using Langmuir isotherm. The information gathered from the analysis showed that the corrosion of 500B reinforced bars was inhibited by both alkaloid and saponins to an efficiency of 98.9% and 89.4 %, respectively. This mechanism of adsorption that lead to such inhibition was a physical mechanism as shown by the correlation coefficient and slope values of approximately unity. Inhibition was also confirmed from the increase in charge transfer resistance and decrease in corrosion current density as inhibitor concentration increased. The Gibbs free energy showed a stable metal – inhibitor interface and a reaction that is spontaneous following negative values of the Gibbs energy.

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Corrosion generally come to play in metals when there is gradual conversion into unwanted substances, as a result of chemical and electrochemical responses to its surrounding environment. Moreover, corrosion is unavoidable and prone to the deterioration of metallic substance (Zaher *et al.*, 2020; Solanki *et al.*, 2025). The anodic and cathodic electrochemical reactions are involved in the attack process. A general attack is a uniform electrochemical reaction that happens on the entire surface of a material. Corrosion can occur in pipeline, ship hulls, bronze statues, copper roofs, steel bridges, metallic

equipment, etc (Solanki *et al.*, 2025; Agwamba *et al.*, 2022; Ugi *et al.*, 2022). The factors influencing corrosion in the atmospheric zone are temperature, humidity, steel type, ventilation, pressure, carbon dioxide, sulphuric acid, oxygen, sulfur dioxide, and chloride concentrations (Tan *et al.*, 2020; Sahama *et al.*, 2021; Nya *et al.*, 2018; Joshi *et al.*, 2021). Due to all these factors, a good maintenance strategy is always sorted for in order to detection and maintenance corrosion activities. The cost of corrosion is high and estimated to be billions of dollars, which burdens the related industry if it is not

*Correspondence author: ugibenedict@gmail.com

*ORCID: <https://orcid.org/0000-0003-0697-8280>

*Tel: +2347067921098

detected in the early stage (Zaher *et al.*, 2020; Solanki *et al.*, 2025). Most of the organic/inorganic compounds containing elements of groups VB, VIB or functional groups of the type amine, carbonyl and alcoholic groups are more effective corrosion inhibitors. The inhibitor is adsorbed on the entire metal surface and so prevents attack of the metal (Solanki *et al.*, 2025).

Reinforcing bars, or rebar as they are also referred to, are manufactured from 500B grade mild steel that conforms to the BS 4449:2005 specification. Reinforcing bars are used as a tension device in reinforced concrete and masonry structures (Bhoomik *et al.*, 2025; Bandeira *et al.*, 2025). Rebar strengthens the structure by holding the concrete in a compressed state. Concrete is strong under compression but has relatively weak tensile strength, setting rebar into the concrete significantly increases the tensile strength of the structure. Mild steel and concrete have similar coefficient thermal expansion properties, this reduces internal stress caused by changes in temperature to strengthen the structure, maintain the integrity of the construction and reduce or limit cracking (Bhoomik *et al.*, 2025; Bandeira *et al.*, 2025). Consequently, The objective of this paper was to evaluate the corrosion inhibitor potential of tropical milkweed (*Asclepias Curassavica*) plant leaf extracts for reinforced bars in chloride concentrated environment.

MATERIAL AND METHODS

Sample Material: *Asclepias curassavica* (Tropical milkweed) is an annual or short-lived perennial plant tropical plant with stems that are usually unbranched but sometimes with several branches. The stems are usually 40 - 150cm tall, occasionally to 250cm, and usually become more or less woody at the base. The plant is widely cultivated throughout the tropics as an ornamental, but it is also sometimes grown, in places such as China, as a medicinal plant. The root contains a glycoside, asclepiadin, which is emetic and purgative - in large doses it can cause death. The plant is suspected to be poisonous to grazing animals. It occurs most frequently in pastures, wastelands and along roadsides at elevations from sea level to over 1,500 metres.

The fresh leaves of *Asclepias Curassavica* leaves were used in this study (Huxley, 1992).

Material pretreatment: The reinforced steel sheet used for this experiment has the following chemical composition as in table 1. The reinforced steel which was resized to a dimension of 2.0 x 0.08 cm had its initial corroded surface removed by polishing to a mirror surface through the use of a UNIPOL- 820

metallographic polishing machine carrying different grits of silicon carbide papers (400 grits – 1200 grits).

Table 1: Chemical composition of Reinforced steel bar 500B

Metal	Composition (%)
Carbon (C)	0.19
Silica (Si)	0.26
Sodium (Na)	0.64
Sulphur (S)	0.05
Phosphorus (P)	0.06
Nickel (Ni)	0.09
Chromium (Cr)	0.08
Molybdenum (Mo)	0.02
Copper (Cu)	0.27
Iron (Fe)	98.3

This was followed by washing through a running tap with the use of a bristle brush, degreased in absolute ethanol, rinsed in acetone before air-drying and stored in a moisture free desiccator prior to the corrosion examination. All reagents used were of analytical grade and distilled water was used throughout the experiment. The fresh *Asclepias Curassavica* leaves were chopped into small pieces after being washed and then dried in an oven at 40⁰ C. In most cases, dried sample is preferred considering the time needed for experimental design. After drying of the leaves, conventional mortar and pestle was used for grinding, followed by the use of electric blender to reduce particle size of sample since lowering particle size increases surface contact between samples and extraction solvents.

Extraction of alkaloid: An ADAM PGW 253e electronic digital weighing balance was deployed in the weighing of 50 g of powdered *Asclepias Curassavica* leaves into a 500 cm³ beaker. Into the beaker, 200 ml of 10 % acetic acid in ethanol was added, covered and allowed to stand for 5 hours. The mixture was then filtered and the extract (the filtrate) was concentrated on a water bath to 25 % of the original volume. This was followed by the addition of concentrated ammonium hydroxide drop wise to the filtrate until a precipitate was formed. The precipitate was then collected and washed with dilute ammonium hydroxide and then filtered. The residue collected was the alkaloid fraction which was then dried and weighed out by 5 g for the preparation of the various inhibitor concentrations (1000 ppm, 2000ppm, 3500 ppm, 5000 ppm, 7000 ppm).

Extraction of saponins: 50 g of plant sample was dispersed in 150 cm³ of 20 % ethanol. The suspension was then heated over a hot water bath for 5 hours with continuous stirring at 50⁰ C. The filtrate and the residue were extracted with another 100 ml of 20 % ethanol and the concentrate to 30 ml over a water bath at 75⁰ C. The concentrate was transferred

UGÍ, B. U; OJÍ, N. N; UGÍ, F. B; UGI, D. U; TAMUNOTONYE, G. T

into a 250 cm³ separating funnel and 50 cm³ of diethyl ether was added and shaken vigorously. The aqueous layer was recovered and the ether layer discarded while 50 cm³ of n – butanol was added and the extract was washed twice with 20 cm³ of 10 % aqueous sodium chloride and the remaining solution was heated in a water bath for evaporation of the n – butanol fraction. 5 g of the evened dried saponin fraction was then weighed out using ADAM PGW 253e electronic digital weighing balance and used for the preparation of various inhibitor concentrations (1000 ppm, 2000ppm, 3500 ppm, 5000 ppm, 7000 ppm).

Preparation of inhibitor solution: From each of alkaloid and saponins fractions, 5 gm of the sample was separately weighed and dissolved in a 1000 cm³ round bottom flask. 0.5 M hydrochloric acid solution was measured and emptied into same flask, shaken and kept for 24 hours. The mixture was filtered using a filter paper and the filtrate used as the inhibitor solution.

Electrochemical experiment: A computer-controlled potentiostat/galvanostat (Autolab PGSTAT 302N) consisting of saturated calomel electrode (SCE) as reference electrode (RE), platinum as counter electrode (CE) and API 5CT Carbon Steel sheets as working electrode (WE) was used. Before each potentiodynamic polarization (Tafel) study, the electrode was allowed to corrode freely and its open circuit potential (OCP) was recorded as a function of time up to 1 hour, which was sufficient to attain a stable state. Potentiodynamic polarization studies were conducted from cathodic to the anodic direction on the potential range ± 250 mV versus corrosion potential (E_{corr}) at a scan rate of 10 mV/s. Linear polarization resistance measurements (LPR) were carried out at the potential range ± 20 mV with respect to the open circuit potential, and the current response was measured at a scan rate of 0.5 mV/s. The EIS measurements were performed once the OCP was stabilized at a frequency range of 100 KHz to 10 MHz with a signal amplitude perturbation of 5 mV. The inhibition efficiency (%) from PDP was calculated from the measured I_{corr} values using equation 1.

$$I(\%) = \left(\frac{A_{corr}^0 - A_{corr}}{A_{corr}^0} \right) \times 100 \quad (1)$$

Where A_{corr}^0 = corrosion current densities in the absence of Schiff base ligand; A_{corr} = are the corrosion current densities in the presence of Schiff base ligand; The polarization resistance was obtained using the Stern-Geary equation 2.

$$R_p = \frac{C_a * C_c}{2.303 * I_{corr} * (C_a + C_c)} \quad (2)$$

where C_a and C_c are the anodic and cathodic Tafel slopes. From the measured R_p values, the inhibition efficiency (%) was calculated using Equation 3.

$$I(\%) = \left(\frac{R_p - R_p^0}{R_p} \right) \times 100 \quad (3)$$

where R_p^0 and R_p are the polarization resistance values in the absence and presence of inhibitors.

The constant phase element which is defined by Y_o and n has correlation with the impedance as follows equation 4

$$ZZ_{CPE} = Y_o^{-1}(j\omega)^{-n} \quad (4)$$

where Y_o = the CPE constant and n = the CPE exponent, $j = (-1)^{1/2}$ which is an imaginary number and ω = the angular frequency in rad/s. The double layer capacitance (C_{dl}) values were calculated from equation 5 expression.

$$C_{dl} = \frac{1}{\omega R_{ct}} = \frac{1}{(2\pi f_{max} R_{ct})} \quad (5)$$

Where ω is the angular frequency ($\omega = 2\pi f_{max}$), f_{max} is the frequency at which the imaginary component of the impedance is maximum. The inhibition efficiency acquired from the impedance spectroscopy measurements were calculated using equation 6:

$$\%IE = \frac{A_{ct(inh)} - A_{ct}^0}{A_{ct(inh)}} \times 100 \quad (6)$$

Where $A_{ct(inh)}$ and A_{ct}^0 = the charge transfer resistance in the presence and absence of inhibitor, respectively.

RESULTS AND DISCUSSION

Weight loss: From Tables 2, it was observed that the loosely bounded particles of the metal were affected by the acid attack especially where there was no inhibitor introduced. This could be due to the accumulation of dissolved non - volatile metal particles in solution with time (Ugi *et al.*, 2024; Bhoomik *et al.*, 2025; Bandeira *et al.*, 2025; Rbaa *et al.*, 2020). However, it was not the case when the inhibitor was added as the weight loss eventually began to decrease with time implying that the presence of the inhibitor gave rise to the reduction in the flow of electron from the anode. This is again attributed to stronger inhibitor adsorption on the

surface withholding the process of dissociation of loosely held particles (Ugi *et al.*, 2024; Bhoomik *et al.*, 2025)

Table 2: Result for weight loss analysis

	Conc. (ppm)	CR (mg/cm ² /hr)	Θ	Inh. Eff. (%)
CAAC	Blank	99.001	-	-
	1000	32.461	0.672	67.2
	2000	21.521	0.783	78.3
	3500	13.479	0.864	86.4
	5000	6.795	0.931	93.1
	7000	1.442	0.985	98.5
	1000	40.101	0.595	59.5
CSAC	2000	29.068	0.706	70.6
	3500	17.906	0.819	81.9
	5000	10.647	0.893	89.3
	7000	7.130	0.928	92.8

Ppm = path per million; Cr = Corrosion rate; Θ = Surface coverage; Inh. Eff. = Inhibition efficiency

Reaction rate analysis: In order to understand the kinetics governing the inhibitor-metal interface in the corrosion inhibition process, plots of weight loss of reinforced steel bar 500B against the time of immersion of the metal in hydrochloric acid was drawn (Uwah *et al.*, 2013; Fouda *et al.*, 2021; Ameh and Eddy 2018). A first order kinetics was proposed from the perfect linearity of the plots. The equation of the first order kinetics in which the data was fitted is shown in Equation 7.

$$\ln(W_f/W_o) = -kt \quad (7)$$

where k is the rate constant.

The values of the rate constants k obtained from the slope of the plot are presented in Table 2. There was a clear evidence of decreasing rate constant with respect to an increased inhibitor concentration as seen in Table 3. This shows that both the alkaloid and saponin inhibitors acted as reliable corrosion inhibitors of reinforced steel bar 500B with a slower corrosion reaction rate. This result is in agreement with that obtained from corrosion rate values calculated using weight loss technique. The half life values as shown in Table 3 were calculated using Eq. 8. There was an observable increase in the half life values with respect to increasing inhibitor concentration. This observation can be attributed to the strong inhibitor adsorption on the surface of the reinforced steel bar 500B with little effect of aggritation due to temperature rise (Su *et al.*, 2020; Solanki *et al.*, 2025; Ugi, 2024) since the greater the extract concentration, the more time it takes for the reinforced bars to corrode to half the original size.

$$t_{\frac{1}{2}} = \frac{0.693}{k} \quad (8)$$

Table 3: Kinetic data for the reaction of CAAC and CSAC on reinforced bars in HCl

System (ppm)	Alkaloids	Saponins	K (Hrs) x 10 ⁻³	t _{1/2} (Hrs)
	K (Hrs) x 10 ⁻³	t _{1/2} (Hrs)		
Blank	5.63	122.9	3.63	190.6
1000	4.46	155.2	3.33	207.8
2000	2.02	342.6	3.21	215.6
3500	1.75	395.4	2.42	285.9
5000	1.45	477.2	2.25	307.6
7000	1.19	581.5	2.13	324.9

K = Rate constant; t_{1/2} = Half life

Table 4: EIS values for the Corrosion Management of 500B Reinforced Bars in Chloride Concentrated Environment using CAAC and CSAC of *Asclepias Curassavica*

	Conc. (ppm)	R _{ct} (Ωcm ⁻²)	C _{dl} (μFcm ⁻²)	% IE
CAAC	Blank (0.5 M HCl)	99	1.6 x 10 ⁻⁵	-
	1000	153	1.0 x 10 ⁻⁵	35.3
	3500	278	5.7 x 10 ⁻⁶	64.4
	7000	604	2.6 x 10 ⁻⁶	83.6
CSAC	Blank (0.5 M HCl)	99	1.6 x 10 ⁻⁵	-
	1000	150	1.1 x 10 ⁻⁵	34.0
	3500	201	7.9 x 10 ⁻⁶	50.8
	7000	519	3.1 x 10 ⁻⁶	80.9

Electrochemical impedance result: Data for the electrical interference of the system with the inhibitor are presented in Table 4 and the corresponding Nyquist plots are shown in Figures 1 - 2. It was observed that the inhibitor presented a single capacity loop for 500B reinforced bar which is directed towards a single charge transfer (Bandeira 2025; Ammouchi *et al.*, 2020; Ameh *et al.*, 2025). The sizes of these loops were observed to increase up to 7000 ppm which is in line with the increased charge transfer values indicating an adsorption of both the CAAC and CSAC on the reinforced bar surface and a reduction of the exposed active sites (Bandeira 2025; Ammouchi *et al.*, 2020). The data for the double-layer capacitance of the semicircle and inhibition efficiency were determined following equation 9 to 10 and are presented in Table 4 to 5.

$$C_{dl} = \frac{1}{\omega Z''} \quad (9)$$

where Z'' is imaginary component of impedance at any frequency inside the semicircle and ω is the angular frequency (Bandeira, 2025; Ameh *et al.*, 2025).

$$\% Q = \frac{\frac{Z_{ct}^0}{\omega} - \frac{Z_{ct}^i}{\omega}}{\frac{Z_{ct}^0}{\omega}} \times 100 \quad (10)$$

UGÍ, B. U; OJÍ, N. N; UGÍ, F. B; UGI, D. U; TAMUNOTONYE, G. T

Where z_{ct}^0 and z_{ct}^i correspond to the charge transfer values in the free and inhibited solutions of inhibitors respectively.

Values from Table 4 showed increased charge transfer resistance as for the reinforced bars as increased concentration increases. The increase values of the charge transfer resistance with inhibitor

concentrations implies that a greater difficulty and energy lost was encountered during the inhibition process as the electrochemical process was effected, hence strong surface adsorption as well as inhibition of corrosion active sites in the reinforced bars took place (Ebenso *et al.*, 2021; Ugi *et al.*, 2025; Krishnanjana and Ganesh, 2025; Ugi *et al.*, 2021).

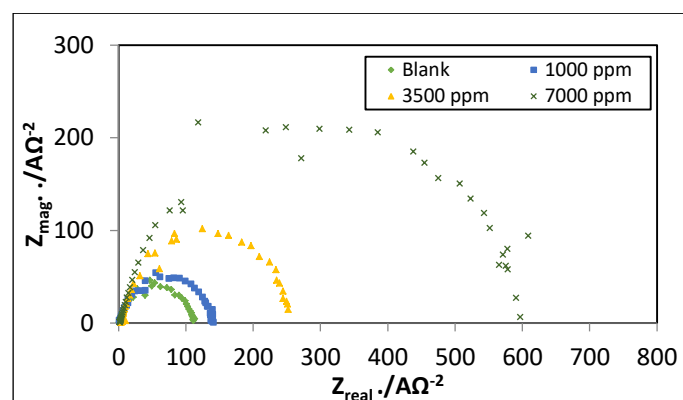


Fig. 1: Nyquist plots for the Corrosion Management of 500B Reinforced Bars in Chloride Concentrated Environment using Alkaloids of *Asclepias Curassavica*

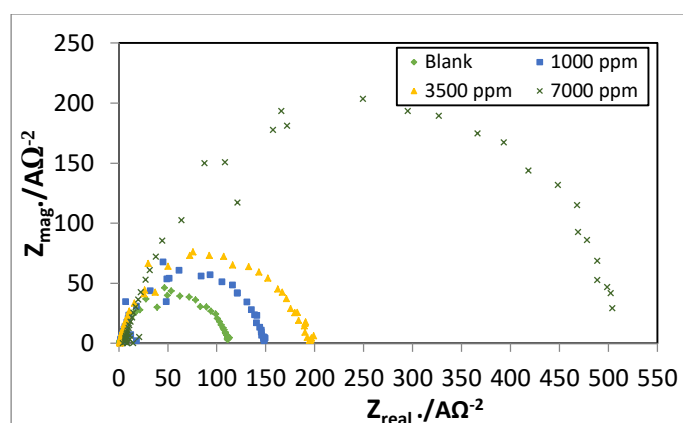


Fig. 2: Nyquist plots for the Corrosion Management of 500B Reinforced Bars in Chloride Concentrated Environment using Saponins of *Asclepias Curassavica*

Potentiodynamic polarization (PDP) result: Literature shows that a higher value of corrosion density and or more negative value of the corrosion potential would indicate that the coating – inhibitor system has less resistance to corrosion (Bashir *et al.*, 2020; Ugi, 2014;2021; Eteeb *et al.*, 2021). The given values from Table 3 shows otherwise as corrosion current density values in the presence of the inhibitors are lower than those in the absence of inhibitor and the values also decrease as the inhibitor concentration increases. This describes both inhibitors as very effective as they exhibited a higher

corrosion resistance (Diki *et al.*, 2021; Lui *et al.*, 2020; Ugi *et al.*, 2020). Again, It was confirmed that the corrosion potential values were shifted gradually to a more positive direction at every addition of the inhibitor, and also shows changes in both the cathodic and anodic polarization branches (Figs. 3 - 4). This as an indication that the added inhibitor molecules acted majorly as an anodic type inhibitor (Bhoomik *et al.*, 2025; Bhuvaneswari *et al.*, 202; Majda *et al.*, 2020). This can also be confirmed from the anodic and cathodic Tafel slope values in Table 3

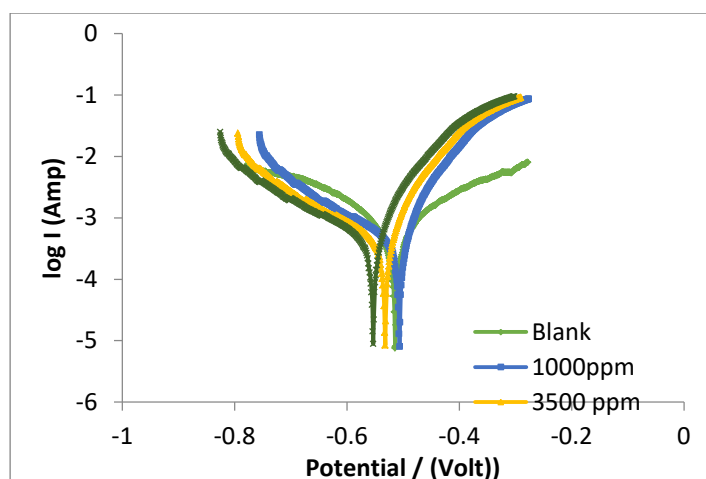


Fig. 3: Tafel plots for the Corrosion Management of 500B Reinforced Bars in Chloride Concentrated Environment using Alkaloids of *Asclepias Curassavica*

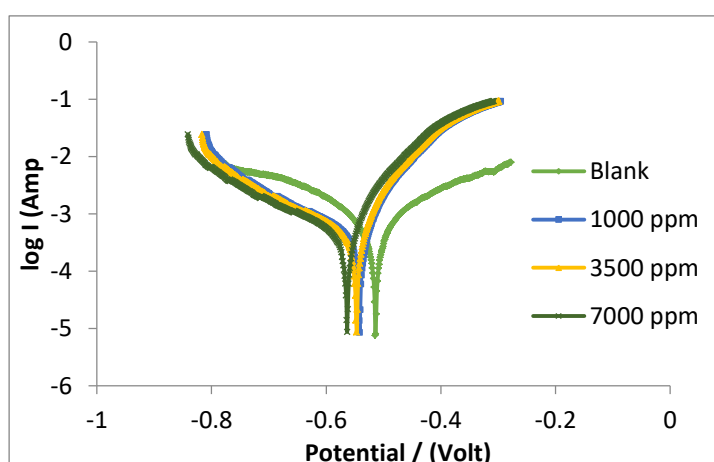


Fig. 4: Tafel plots for the Corrosion Management of 500B Reinforced Bars in Chloride Concentrated Environment using Saponins of *Asclepias Curassavica*

Table 5: Values of PDP for the Corrosion Management of 500B Reinforced Bars in Chloride Concentrated Environment using Alkaloids and Saponins of *Asclepias Curassavica*

	Conc. (ppm)	I_{corr} (mAcm ⁻²)	E_{corr} (mV)	θ	IEi (%)
CAAC	Blank (0.5 M HCl)	1.917	-216.4	-	-
	1000	0.153	-201.9	0.920	92.0
	3500	0.108	-181.5	0.944	94.4
	7000	0.084	-147.3	0.956	95.6
CSAC	1000	0.216	-200.8	0.887	88.7
	3500	0.175	-166.5	0.909	90.9
	7000	0.119	-139.4	0.938	93.8

I_{corr} = Corrosion current density; E_{corr} = Corrosion potential; IEi = Inhibition efficiency

Langmuir adsorption isotherm determination: In understanding corrosion inhibition between interfaces (metal – inhibitor interface), the standard adsorption Gibbs free energy is often estimated through the linear regression of the Langmuir isotherm where both the intercept and the slope are estimated (Ugi and Abeng, 2013; Solanki *et al.*, 2025; Onyeachu *et al.*, 2021; Ugi *et al.*, 2024). The Langmuir isotherm is given in the equation 11

$$\frac{C}{\theta} = \frac{1}{k} + c \quad (11)$$

Where C = concentration of inhibitor, θ = surface coverage of inhibitor and k is equilibrium constant. Langmuir isotherm requires that the slope be approximately unity for attractive interaction between metal and inhibitor since repulsive interaction, multiple site adsorption, or surface homogeneity result in a slope greater than 1 (Ebenso *et al.*, 2021; Ugi and Ugi 2023; Padash *et al.*, 2020). From Figure

UGÍ, B. U; OJÍ, N. N; UGÍ, F. B; UGI, D. U; TAMUNOTONYE, G. T

5, it is observed that the slope values are approximately unity for both inhibitors hence establishing both inhibitors as having a strong attractive interaction (adsorption) between the reinforced bars and the inhibitor (Krishnanjana and Ganesh, 2025; Zahar *et al.*, 2020; Ugi and Magu, 2017). The regression coefficient is 0.999 which indicate that the inhibitor obeyed perfectly the Langmuir isotherm, hence are physically adsorbed

and demonstrated a physical adsorption mechanism (Ugi *et al.*, 2016). The values of the Gibbs free energy are more negative than -20 kJ/mol. This is an indication that the inhibitors actually adsorbed physically as illustrated with the regression coefficient, and are stabled on the metal surface and the reaction is spontaneous (Bandeira *et al.*, 2025; Sharma *et al.*, 2021).

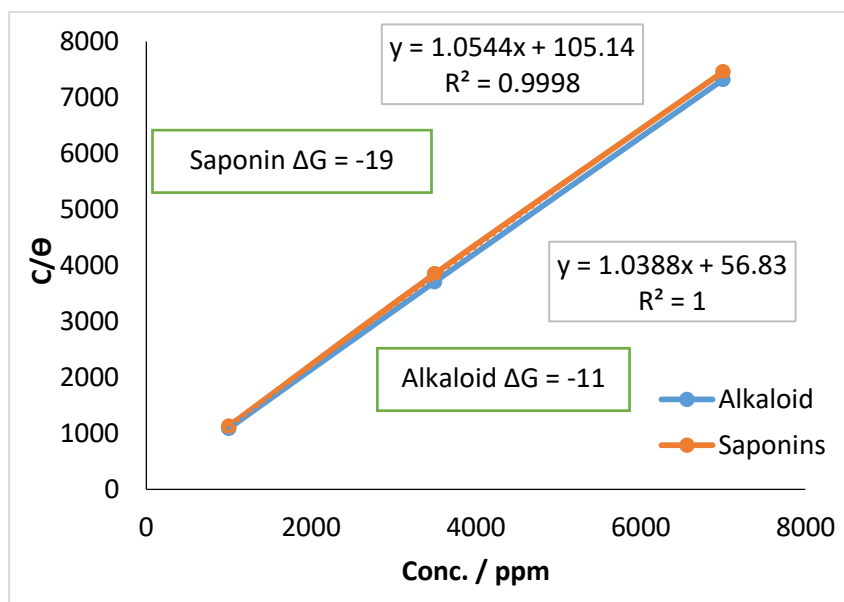


Fig. 5: Langmuir adsorption plots for the Corrosion Management of 500B Reinforced Bars in Chloride Concentrated Environment using Alkaloids and Saponins of *Asclepias Curassavica*

Conclusion: The inhibition values obtained from the surface treatment of reinforced bars with alkaloid and saponins of *Asclepias Curassavica* leaves shows 98.9% and 89.4 % efficiency portraying a reliable inhibitor. This asertion is dawn from most important factors like increased charge transfer resistant values, reduced repulsive interaction, multiple site adsorption and surface homogeneity. Potntiodynamic polarization showed corrosion current density values in the presence of the inhibitors to be lower than those in the absent of inhibitor and the values also decreases as the inhibitor concentration increases, describing both inhibitors as very effective as they exhibited a higher corrosion resistance. Values of the Gibbs free energy were more negative than -20 kJ/mol, indicating that the inhibitors adsorbed physically. are stabled on the reinforces bars surface and the reaction is spontaneous.

DECLARATION

Ethical Approval: This study did not involve human participants or animal experimentation and therefore did not require formal ethical approval. All procedures involving data handling and analysis were

conducted responsibly and in accordance with standard academic and institutional guidelines.

Disclaimer (Artificial Intelligence): Author(s) hereby declare that no generative *Artificial Intelligence* (AI) technologies such as Large Language Models (ChatGPT, COPILOT, XLNet, Ernie 3.0 Titan etc) and text-toimage generators have been used during writing or editing of this manuscript.

Declaration of Conflict of Interest: The authors declare that no known conflict of interest or personal relationships that have influence the work reported in this paper.

Declaration of Data Availability: Data are available upon request from the corresponding Author.

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