PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 30 (3) 882-891 March 2026

Anti-Corrosive potential of Luffa Cylindrical (*Sponge gourd*) fruit ethanol extract as paint additive on metal pipeline in acid and aqueous media

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ABSTRACT: Metallic materials are the most widely used materials in various industries, which are susceptible to corrosion due to environmental factors, consequently; the objective of this paper was to investigate the anti-Corrosive potential of Luffa Cylindrical (*Sponge gourd*) fruit ethanol extract as paint additive on metal pipeline in acid and aqueous media using appropriate standard procedures such as weight loss. The inhibition efficiency increased as the concentration of *luffa cylindrica* extract were increased but highest corrosion inhibition was recorded in pipeline water with 98.99% while in HCl it was 86.31% at 5g/l due to increased concentration. The results showed that at 5g/l paint 5 has the highest corrosion rate of 0.044 mm/yr in pipeline water as compared to Paint 1 with 0.00491 mm/yr in pipeline water. Paint 5 with inhibitor concentration of 5g/l was proposed as the most effective paint that contains a natural inhibitor for pipeline steel in the entire medium.

DOI : https://dx.doi.org/10.4314/jasem.v30i3.31

Cite this Article as: OTHAKI, E. P; OKOROSAYE-ORUBITE, K; NGOBIRI, N. C. (2026). Anti-Corrosive potential of Luffa Cylindrical (*Sponge gourd*) fruit ethanol extract as paint additive on metal pipeline in acid and aqueous media. *J. Appl. Sci. Environ. Manage.* 30 (3) 882-891

Dates: Received: 09 February 2026; Revised: 13 March 2026; Accepted: 24 March 2026; Published: 31 March 2026

Keywords: Corrosion inhibition; gravimetric; adsorption; pipeline steel; paint; pipeline water

Metals have been very useful in the evolution of mankind for many centuries. It was shaped into various tools, ornaments and weapons by prehistoric people. Interestingly, it still have numerous uses till date. Corrosion of metals has however cramped the joy that comes with exploring the various uses of metals in the society today. It has led to fatal mechanical breakdown of equipment and metallic structures due to their interaction with acidic and alkaline environment (Abdel-Gaber *et al.,* 2011). Various methods have been introduced to solve this problem of corrosion in the society. One of the prominent solutions to corrosion is the use of corrosion inhibitors. These inhibitors are usually added in little quantity or drop to impede the corrosion rate of metallic structures. Research has shown that "Plant extracts" are very good corrosion inhibitors. They are classified as green inhibitors due to their environmental friendly nature and they have shown great result in mitigating corrosion. They can be gotten through several extraction techniques like cold extraction, maceration, soxhlet extraction, supercritical liquid extraction, etc (Al-Amiery *et al*., (2022); Al-Otaibi, *et al*., 2012).

The hazard called corrosion has led to the inefficiency of equipment, decrease in the quality, malleability, durability and ductility of metallic structures. Corrosion of pipeline steel is a major problem for industries in the society, this is due to its wide use in various industries as it is cost effective and has good mechanical properties compared to

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other metals or alloys. Therefore, the need to protect it from corrosion is vital. Pipeline steel coated with green inhibitor is an efficient, cheap and environmental friendly approach to prevent corrosion (Bhat, and Pujari, 2001).

The *Luffa aegyptiaca (sponge gourd)* specie has been severally reported as a nutritional and medicinal species (Bhat and Pujari, 2001). Also in literature are its corrosion inhibition characteristics (Cwalina, 2014). An advancement of its corrosion mitigation activity will lead to a competitive demand with negative consequences especially in the developing countries. *Luffa aegytiaca* also known as *luffa cylindrica* , sponge gourd, loofa, dish cloth gourd, bath sponge, and vegetable sponge is an essential vegetable and medicinal plant that belongs to the genus Luffa and plant family Cucurbitaceae. It‟s origin can be traced to tropical Asia. It is a crawling plant that grows in the wild and on abandoned buildings, structures and fence in towns and villages. It is a climbing annual wild vine with lobed cucumber like leaves that are dark green in colour with rough surface. The plant with yellow flowers bear fruits that are cucumber shaped but larger in size and contain fibrous sponge in which holds the hard black seeds (Badawi and Fahim, 2021). It is an important source of carbohydrates, vitamin C, several minerals (such as Mg, Ca, Na, K, Cu, Zn, and Mn), tannin oxalate, phytin phosphorus, and phytic acid and protein in human diet. The leaves, seeds, and fruits of sponge gourd are used in treating various ailments such as viral infections, diarrhea, fever, swells, inflammatory diseases, etc (Othaki and Ngobiri, 2020). Immature fruits are consumed as vegetables which are effective in treating diabetes. The extracts from living vines are used as constituents in cosmetics and medicine. They are used as fillers in producing composite materials. In some cultures, the mature fibrous skeleton of the luffa fruit is used as a natural scrubbing spong for cleaning and bathing. It has been used for centuries as an eco-friendly alternative to synthetic sponges. Matured *Luffa cylindrica* (Sponge gourd) fruit Dried Matured *Luffa cylindrica (*Sponge gourd) fruit. The chemical components of *Luffa aegytiaca* include various bio active compounds such as flavonoids, phenolic acids, and other phytochemicals. These compounds contribute to the several potential health benefits and therapeutic properties of the plant. However, it‟s important to note that there is limited research on the inhibitory properties of sponge gourd. The objective of this paper was to investigate the anti-Corrosive potential of *Luffa cylindrical* (*Sponge gourd*) fruit ethanol extract as paint additive on metal pipeline in acid and aqueous media.

MATHERIALS AND METHODS

Materials: Pipeline Steel (AA5083) specimens were used for this study due to their extensive usage in marine, oil and gas industry, particularly as a plate for ship, pipeline construction. Pipeline Steel (PS) metal sheets was gotten from Metal section of Mile 3 Market Port Harcourt, Rivers State. The specimens were cut into square shapes with dimension of 2.96 cm x 2.5 cm x 0.9 cm. The AA5083 has percentage composition of 0.42% Si, 0.45% Fe, 0.12% Cu, 0.40-1.0% Mn, 4.0-4.9% Mg, 0.05-0.25% Cr, 0.25% Zn and 0.15% Ti. (Mohammed Tariq Saeed *et al.*, 2019). The specimens were polished with 400, 800 and 1200 grade of abrasive paper. The polished specimens were cleaned by using acetone (according to SSPC-SP1 Standard) to remove all visible oil, grease, soil, drawing and cutting compounds, and other soluble contaminants until a mirror like surface was achieved, washed in absolute ethanol and distilled water, rinsed in acetone , dried in air and preserved in desiccators to prevent interaction with the environment. The elemental composition of the metal coupons was analysed using optical electronic spectroscopy (OES) in the Department of Metallurgical and Material Engineering, University of Lagos.

Plant Extraction: The *luffa cylindrica* (fruits) were harvested from uncompleted buildings at different locations (such as Rumuigbo, Ipo, and University of Port Harcourt), Rivers State; washed to remove any earthly materials and contaminants, allowed to dry for seven days. The plant was taxonomically identified at Plant Science and Biotechnology Department, University of Port Harcourt, Nigeria where a voucher specimen submitted. (Othaki and Ngobiri, 2020; Ngobiri, NC *et. al*., 2020).

The fresh fruits were washed with running water, rinsed with distilled water. The fresh fruit samples were grinded using manual blender. The extract were obtained by soaking 100 g of grinded fruit samples for 7 days in 1000 cm^3 beaker containing 500 cm^3 of ethanol. The mixture were first sieve with muslin cloth, the liquid obtained were subsequently filtered using Whatman No 1 filter paper and the filtrate was then_concentrated using a water bath until a solid residue was obtained at 60^oC. The percentage yield of plant extract was found to be 4.65% for LCF. The stock solutions of the extracts so obtained were used in preparing different concentration of the extract ranging in from 1- 5g/L of the inhibitor. The phytochemical in the extract were determined using the preliminary screening method for phytochemicals.

Paint Preparation: WW rosin type resin (colophony) was used as a binder and oleic acid as the plasticiser. The paint was prepared by using a magnetic stirrer to blend all the ingredients together and also to achieve an efficient dispersion. WW rosin and oleic acid were dissolute in a xylene/white spirit mixture (1:1) by using a high speed disperser. The ingredients were then mixed with the pigments and additives (zinc oxide and calcium carbonate), and dispersed for 24 hours (Ngobiri, NC *et. al.*, 2019 : Cwalina, 2014). The paints were diluted with different concentrations of *luffa cylindrica (sponge)* fruit extract. The specimens (pipeline steel) were then coated with epoxy-based paint with the aid of paint brush until a uniform surface was obtained. There are five types of paints used in this study, in which Paint 1 without luffa fruits extract (zero inhibitor) acts as the control paint. Besides that, there are Paint 2, Paint 3, Paint 4 and Paint 5 incorporated with different concentration of *luffa cylindrica (sponge)* fruit extract.

Weight Loss Measurements: *Pre*-weighed and polished Pipeline steel coupons were totally immersed in six 150 ml beakers co4taining same quantity of the test solution with and without the aqueous extract of *Luffa aegyptiaca (sponge gourd)* fruit *at* 303 K in a water bath at a constant time interval for each temperature measurements. They were retrieved, after each interval, brushed under distilled water and absolute ethanol for cleaning off the corrosion products, dried in air after rinsing in acetone and weighed to determine the weight loss. The experiments were carried out in triplicate and the mean values of the weight loss were used for computation. The experiments were done at temperatures of 303k, 313k and 333k to determine the thermodynamics of corrosion process. Also, these methods have been severally reported (Wan Nik *et al.,* 2017; Yu-Zhao Yang *et al.,* 2024).

The weight loss, degree of surface coverage (θ), percentage inhibition efficiency (%), corrosion rate (mpy), and Rate constant (k) were determined using the equations:

$$\text{Weight loss (W)} = (Wi - Wf) \quad (1)$$

Where W_i is the initial weight loss; W_f is the final weight loss

$$\text{Fractional surface coverage } (\theta) = 1 - \frac{Wi}{Wo} \quad (2)$$

Where: W_o = corrosion rates in the absence of inhibitor; W_f = corrosion rates in the presence of inhibitor.

The total surface area of pipeline steel coupon immersed in the solution was calculated as followed:

$$A = 2 * K * M + K * t + 2 * M * t + 2 * \prod * r * t - 2 * \prod * r2 \quad (3)$$

Where A = Total surface area of the coupon immersed in solution; K = length of coupon; M = Width of coupon.

The corrosion inhibition efficiencies, corrosion rate, half-life and rate constant were obtained as shown below.

$$\text{Corrosion inhibition efficiencies (\%IE)} = \frac{Wi}{Wo} * 100 \quad (4)$$

Where: W_o and Wi is weight loss in grams of metal coupon in the presence and absence of various concentration of the extract.

$$\text{Corrosion rate (mpy)} = \frac{87.6 * (w1 - w2)}{D * A * T} \quad (5)$$

Where: w_1 and w_2 are the initial and final weights; D = density of the coupons (g/cm^3); A = surface area of coupons (cm^2) and T = exposure time (hours).

$$\text{Half Life } (t\,1/2) = \frac{0.693}{k} \quad (6)$$

$$\text{Rate Constant (K)} = \frac{2.303}{Time} * \log\frac{w_1}{w_2} \quad (7)$$

RESULTS AND DISCUSSION

Weight Loss, Corrosion Rate, Inhibition Efficiency and Surface coverage and effect of Temperature : The effect of different concentration of the extract of LC fruit extract on pipeline steel in 0.5M HCl was investigated by weight loss method at varied temperature of 303K, 313K and 333K respectively, after 168hours of immersion period and presented in figures 1-6. The figures clearly shows a reduction in weight loss of the metal coupons in the presence of extract compared to its black. The corrosion rate and corrosion inhibition efficiency showed inverse relationship in the presence of Luffa *aegyptiaca (sponge gourd)* fruit extract. The corrosion rate decreased, the corrosion inhibition efficiency, half-life increased with increase extract concentration. The trend reverts with increase in temperature.

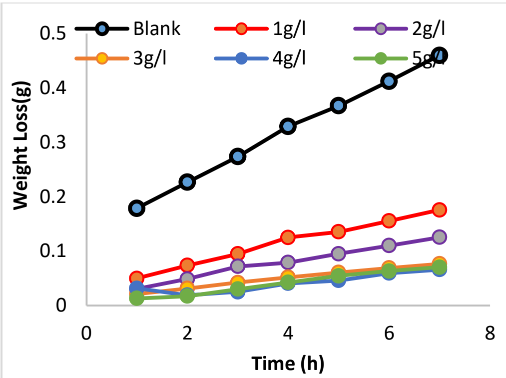

Fig. 1: Plot of weight loss against time for pipeline steel corrosion in 0.5 M HCl with different concentrations of Luffa fruit extract at 303 K.

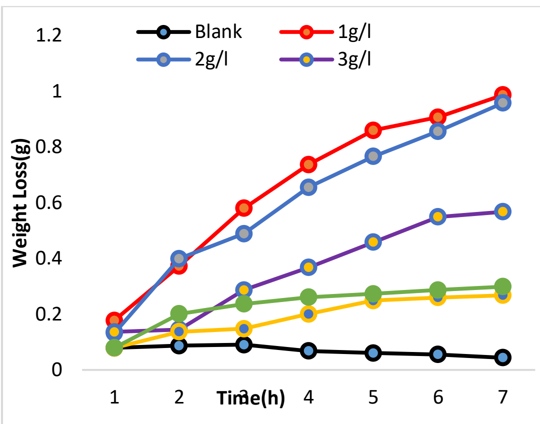

Fig. 2: Plot of weight loss against time for pipeline steel corrosion in 0.5MHCl with different concentrations of Luffa fruit extract at 313 K

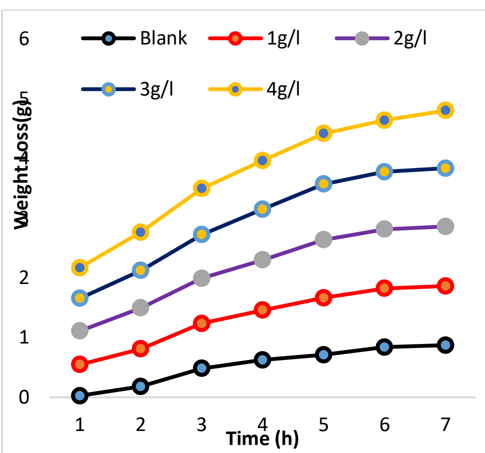

Fig. 3: Plot of weight loss against time for pipeline steel corrosion in 0.5M HCl with different concentrations of Luffa fruit extract at 333 K

The least weight loss was recorded at 5g/l extract concentration and inhibition efficiency of 86.3% in HCl and 98.99% in pipeline water at 303K. Also, similar trends have been reported by researchers (Abdel-Gaber, *et al.*, 2011).

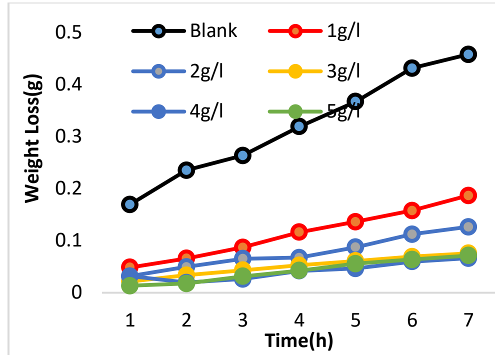

Fig. 4: Plot of weight loss against time for pipeline steel corrosion in pipeline water with different concentrations of luffa cylindrica fruit at 303 K

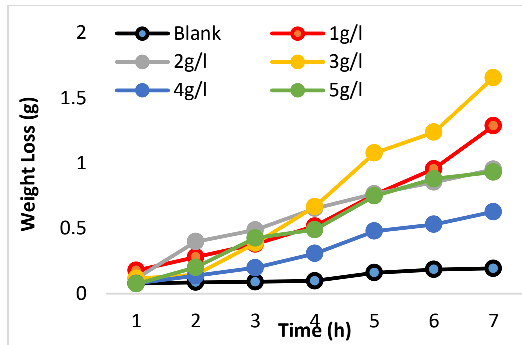

Fig. 5: Plot of weight loss against time for pipeline steel corrosion in pipeline water with different concentrations of luffa cylindrica fruit at 313 K

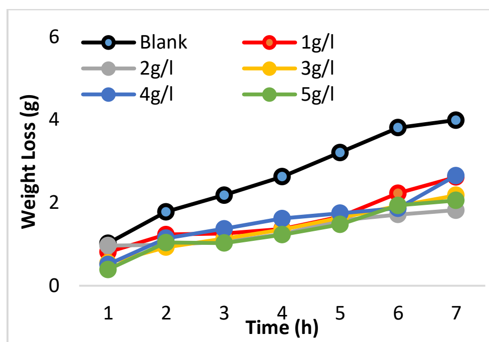

Fig. 6: Plot of weight loss against time for pipeline steel corrosion in pipeline water with different concentrations of luffa cylindrica fruit at 333 K

Adsorption Study: Table 1-2 indicates high degree of surface coverage of the corrosion inhibiting molecules. The mode of their action has been severally attributed adsorption on the metallic surface (Badawi and Fahim, 2021; Cwalina, 2014) In order to determine a suitable mode of adsorption, the corrosion data was fitted into various adsorption isotherms. This is to determine the best fit. The linearity of the plot and good correlation coefficient may suggest that the experimental data for the studied extract fits better a particular adsorption isotherm but consideration of the deviation of the slope from unity shows that the isotherm may not be strictly applied. Several adsorption isotherms were tested, the corrosion of pipeline steel in 0.5HCl and in pipeline water in the presence of LC-fruit extract fitted more to Temkin and Langmuir isotherm..

Table 1: Corrosion rate, inhibition efficiency and degree of surface coverage values deduced from weight loss measurements in HCl solution with luffa fruit extract.

Conc.(s) of Luffa Fruit (g/l)	Corrosion Rate (mm/yr)			Inhibition Efficiency(%IE)			Degree of surface coverage(θ)		
	30°C	40°C	60°C	30°C	40°C	60°C	30°C	40°C	60°C
Paint (blank)	2.395	2.549	2.585	-	-	-			
Paint 1	0.651	0.674	0.957	73.31	73.56	72.84	0.733	0.736	0.728
Paint 2	0.643	0.657	0.934	73.96	74.23	73.15	0.740	0.742	0.731
Paint 3	0.595	0.637	0.903	74.81	75.01	75.14	0.748	0.750	0.751
Paint 4	0.586	0.619	0.877	75.53	75.72	75.52	0.755	0.757	0.755
Paint 5	0.491	0.615	0.580	86.31	75.86	75.79	0.863	0.759	0.758

Table 2: Corrosion rate, inhibition efficiency and degree of surface coverage values deduced from weight loss measurements in pipeline water with luffa fruit extract.

Conc.(s) of Luffa Leaf (g/l)	Corrosion Rate			Inhibition Efficiency(%IE)			Degree of surface coverage(θ)		
	30°C	40°C	60°C	30°C	40°C	60°C	30°C	40°C	60°C
Paint (blank)	1.854	1.866	2.037	-	-	-			
Paint 1	0.509	0.530	0.543	75.01	80.97	71.52	0.750	0.810	0.715
Paint 2	0.049	0.056	0.346	97.59	81.32	72.42	0.976	0.813	0.724
Paint 3	0.049	0.049	0.338	97.61	81.79	72.55	0.976	0.818	0.726
Paint 4	0.048	0.048	0.323	97.64	82.59	72.69	0.976	0.826	0.727
Paint 5	0.044	0.047	0.306	98.99	83.51	72.76	0.977	0.835	0.728

Notably, is the decrease in corrosion inhibiting capacity of the extract with increase in temperature from 303 to 333K. This trend has been reported by researchers (Abdel-Gaber *et al.*, 2011). Thermodynamically, increase in temperature increases the kinetic energy of reacting entities. Therefore, it is expected to increase the rate of oxidation of the steel in acidic environment and pipeline water, reducing the efficacy of the extract in inhibiting corrosion. However, there is a balance of the increased oxidation of the iron in acid environment, pipeline water and the inhibitive action of the LC fruit extract at higher temperature. The constituents of LC extract contains phytochemicals such as alkaloids, terpenes, flavonoids, tannins, etc.

These have fused benzene rings and heteroatoms in the rings, the chemical complexity of the extracts makes it difficult to assign the inhibiting action to a particular constituent. (Othaki and Ngobiri, 2020) . Increase in corrosion rate as the temperature increase has been attributed to desorption of the inhibitive molecules at higher temperature (Ngobiri *et al.*, 2019). This corroborated with the surface coverage data in Table 1- 2.

The overall consequence is increased corrosion rate at higher temperature though the extract still shows active inhibitive presence. The Temkin adsorption isotherm assumes a uniform distribution of adsorption energy, which increase with increased surface coverage is given by equations 8 to 10.

$$\mathrm{Exp}\,(-2 * a * \theta) = \mathrm{Kads} * \mathrm{C} \quad (8)$$

$$-2 * a * \theta = \mathrm{InKads} + \mathrm{InC} \quad (9)$$

$$\theta = \left(\frac{1}{2 * a}\right) * \mathrm{Log\ Kads} - \left(\frac{1}{2 * a}\right) * \mathrm{lnC} \quad (10)$$

where a = the molecular interactions of the adsorption layer and heterogeneity of the coupons; K_{ads} = equilibrium constant, C concentration of extracts, θ = degree of surface coverage. A Plot of surface coverage (θ) against In C at varying temperatures are presented in Figs.7-8. And coefficient (R^2) value greater than 0.960 in HCl, 0.972 in pipeline water are shown in table 3.

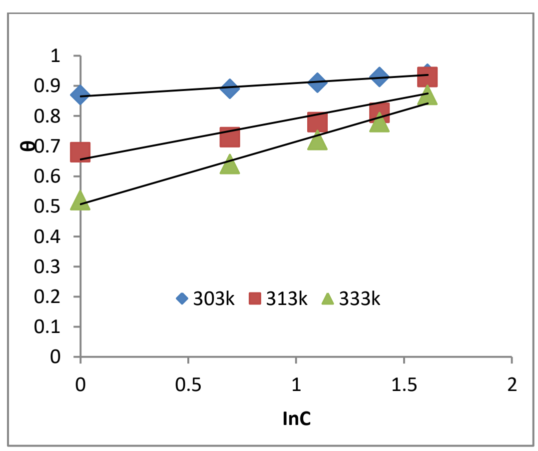

Fig.7: Temkin adsorption isotherm for pipeline steel corrosion of luffa fruit extract in 0.5 M HCl at 303 K, 313 K and 333 K

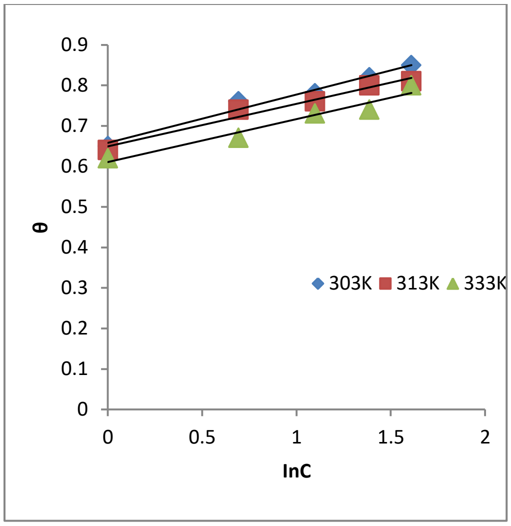

Fig. 8: Temkin adsorption isotherm for pipeline steel corrosion in pipeline water with luffa fruit extract at 303 K, 313 K and 333 K

Figure 9- 10 shows the linear plot of C/θ against C obtained by Langmuir adsorption isotherm equation as shown

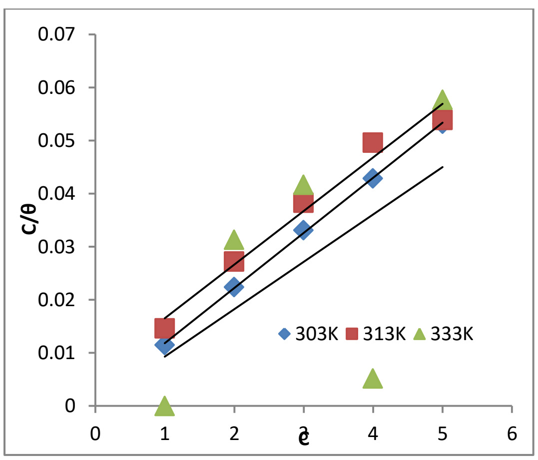

Fig. 9: Langmuir adsorption isotherm of pipeline steel in 0.5M HCl with luffa fruit extract at 303 K, 313 K, and 333 K.

These suggest some measure of conformity of the data to the Temkin adsorption isotherm model. The values of molecular interactions are all greater than zero (›0) which suggest lateral interaction between the pipeline steel and the extract. The LC fruit extract fitted into the Langmuir adsorption isotherm with correlation coefficient (R^2) value of 0.999 which shows a better fit than Temkin isotherm, as shown in Table 4. The values of $\Delta G^o_{ads}$are all negative ranging from -10.543 -10.689kJmol^{-1} in HCl and -10.574 -10.789kJmol^{-1} in pipeline water medium.

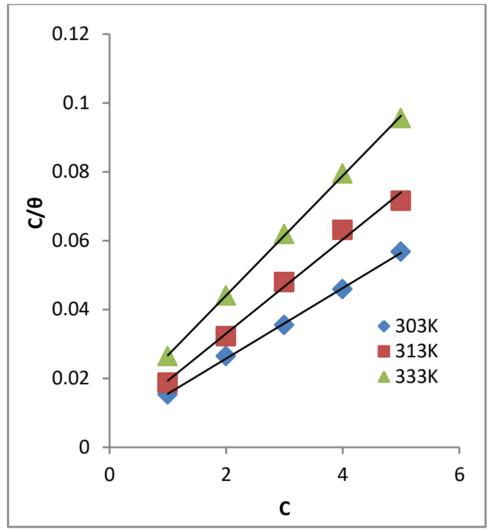

Fig. 10: Langmuir adsorption isotherm of pipeline steel in pipeline water with luffa fruit extract at 303 K, 313 K, and 333 K.

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

Where: K is the equilibrium constant, C is the concentration of the extracts and θ is the degree of surface coverage.

The values of ΔG^o_{ads} are often used to suggest either chemisorptions, physisorption or both adsorption modes.

Physisorption is linked to electrostatic interactions between charged extracts molecules and charged metal surface, while chemisorptions has to do with charge sharing between the metal surface and the extracts molecules resulting in special kind of coordinate bond (Wan Nik *et al.*, 2017). A value of ΔG^oads around 20kJmol^{-1} or less implies physisorption while around 40kJmol^{-1} or greater suggest chemisorptions. However the values of ΔG^o_{ads} obtained as showed in Table 4 are less negative than -20kJmol^{-1}, suggesting physiosorption mechanism. Plots of ΔG^o_{ads} against T are shown in figure 11 from which the ΔH^o_{ads} and ΔS^o_{ads} values were obtained. ΔH^o_{ads} representing the slope and ΔS^o_{ads} as the intercept and the values were - 1.94 and -66 kJmol^{-1} in HCl, - 1.98 and -68 kJmol^{-1} in pipeline water.

Table 3: Some parameters of the linear regression between θ and In C

Tem(K)	HCl Fruit			Luffa fruit extract in pipeline water		
	K_{ads}	A	R^2	K_{ads}	A	R^2
303	0.883	0.816	0.960	0.983	0.887	0.972
313	0.997	0.913	0.980	0.998	0.963	0.987
333	1.09	1.061	0.990	1.29	1.161	0.998

Table 4: Calculated parameters from Langmuir adsorption isotherm plot for pipeline steel in 0.5M HCl of the extracts.

Temp(K)	HCl fruit				Luffa fruit extract in pipeline water			
	K_{ads}	ΔG_{ads}	Slope	R^2	K_{ads}	ΔG_{ads}	Slope	R^2
303	1.174	-10.543	0.99	0.986	1.185	-10.574	0.995	0.988
313	1.133	-10.685	0.99	0.996	1.154	-10.786	0.998	0.997
333	0.962	-10.689	1.125	0.999	0.985	-10.789	1.137	0.999

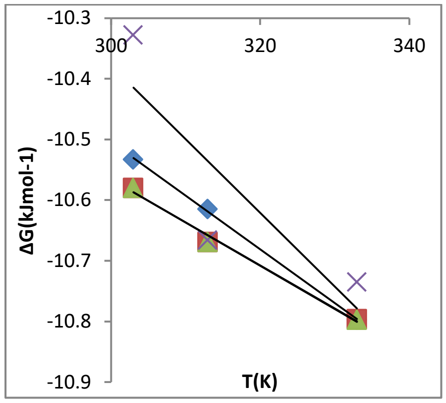

Fig. 11: Langmuir Isotherm plot of ΔG^o_{ads} against T (K) for the adsorption of Luffa leaf extracts in acid medium and pipeline water.

From literature report of Al-Otaibi, *et al.*, 2012 that the values obtained confirm exothermic adsorption to be either by physical adsorption or chemical adsorption while endothermic is only by chemical adsorption. Base on numerical values only, physiosorption only manifest when ΔH^o_{ads} value is lower than -40 $kJmol^{-1}$ while chemisorptions is -100 $kJmol^{-1}$ (Al-Otaibi, *et al.*, 2012). The value of ΔH^o_{ads} obtained confirmed physiosorption mechanism while the negative values of ΔS^o_{ads} implies adsorption of the extract on the surface of the coupons resulting in a reduction of the entropy, which agreed with basic thermodynamic principle of lower in entropy for exothermic reaction.

Kinetic and Thermodynamic Parameters: The values were obtained by Arrhenius equation shown

$$\log CR = \log A - \left(\frac{Ea}{2.303 * R * T}\right) \quad (12)$$

$$\log CR = \log A - \left(\frac{Ea}{2.303 * R * T}\right) \quad (13)$$

$$\log \frac{CR}{T} = \left[\left(\frac{R}{Nh}\right) + \left(\frac{\Delta S*}{2.303*R}\right)\right] - \frac{\Delta H*}{2.303*R*T} \quad (14)$$

Where E_a represent activation energy, A, frequency factor, R gas constant and T, absolute temperature, $\Delta H,^*$ enthalpy of activation, ΔS^* entropy of activation. The value of E_a were obtained from the plot of logCR against 1/T as shown in figure 12-13, while ΔS^* and ΔH^* where gotten from the intercept and slope of the plot of log CR/T against I/T shown in figure 14-15. Generally, physisorption is noted when E_a and ΔH^*value in the presence of extract is greater than in the absence of extract while opposite is for chemisorption.

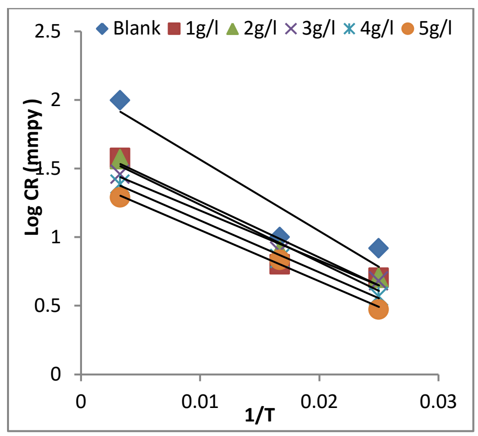

Fig. 12: Arrhenius plot in the absence and presence of different concentrations of luffa fruit extract in HCl

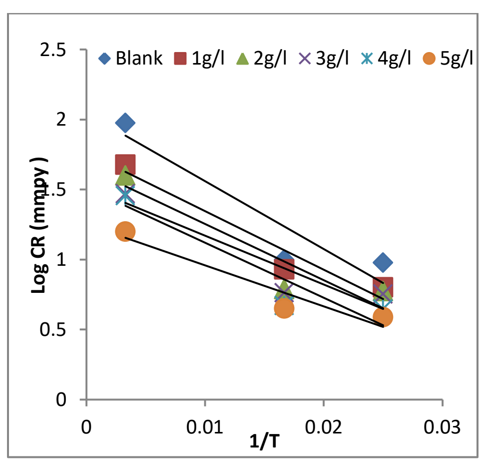

Fig. 13: Arrhenius plot in the absence and presence of different concentrations of luffa fruit extract in pipeline water

Table 5: Activation parameters for pipeline steel in 0.5M HCl and in pipeline water of the extract

Con (g/l)	HCl Fruit					Luffa fruit extract in pipeline water				
	E_a ($kJmol^{-1}$)	ΔH^* ($kJmol^{-1}$)	ΔS^* (Jmol-1)	R^2 (A)	R^2 (T)	E_a ($kJmol^{-1}$)	ΔH^* ($Kjmol^{-1}$)	ΔS^* ($Jmol^{-1}$)	R^2 (A)	R^2 (T)
Paint (blank)	46.27	41.45	-105.35	0.999	0.993	43.72	40.46	-102.08	0.950	0.925
Paint 1	49.59	45.74	-104.66	0.998	0.947	44.91	44.47	-98.89	0.998	0.996
Paint 2	52.78	47.87	-97.47	0.978	0.996	46.59	45.68	-96.56	0.965	0.967
Paint 3	56.51	52.66	-96.66	0.982	0.970	48.67	48.97	-94.82	0.973	0.968
Paint 4	58.29	53.85	-93.45	0.984	0.948	51.98	52.67	-91.56	0.987	0.985
Paint 5	59.06	55.76	-91.67	0.988	0.986	52.87	54.55	-90.78	0.988	0.989

Where A = Arrhenius *T* = Transition

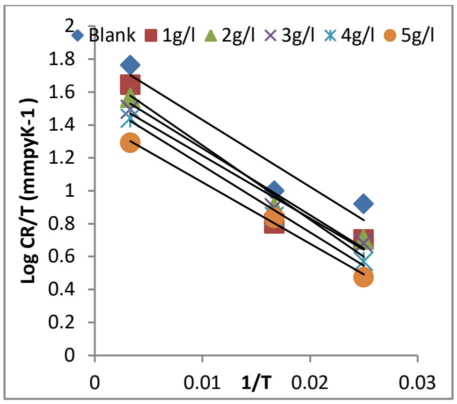

Fig. 14: Transition state plots of pipeline steel in the absence and presence of different concentrations of luffa fruit extract in 0.5M HCl

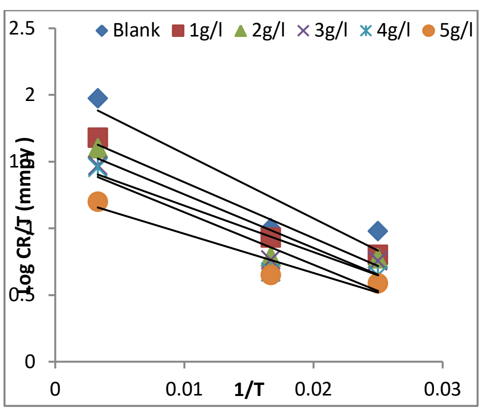

Fig. 15: Transition state plots of pipeline steel in the absence and presence of different concentrations of luffa fruit extract in pipeline water

From Table 5, it is observed that E_a and ΔH^* values in the presence of extract are greater than in the absence validating that physiosorption occur against chemisorption. The activation energy calculated show an increase with increased concentration compared to the blank. The value of ΔS^* were noted to be negative both in the absence and presence of the extract. The negative value of energy of activation for inhibited system has already being reported with hydrogen evolution reaction by Cwalina, B (2014).With increase in negative value of the activation energy in the presence of extract, which increased as the concentration increased (Table 5).

The negative value of ΔS^* signified association rather than dissociation step of activated complex in the rate determining step, signifying a reduction in the degree of disorderliness. (Al-Otaibi, *et al*., 2012).

FT- IR Studies of surface film of pure luffa cylindrica and Luffa cylindrica –fruit on pipeline steel surface in HCl and pipeline water. The FT-IR spectra of the surface film on pipeline steel in the absence and presence of *Luffa cylindrica* fruit extract are presented in Figures 16-18. The functional group(s) in the extract involved in the adsorption process were identified using this method. Before the some striking differences. The pure LC fruit extract spectra have the range of values of 3390-1032, the fruit extract on pipeline steel coupon environment. Immersion of the metals, the projecting spectral peaks provide evidence on the functional groups in the pure extract. After absorption for 12 hours, the peaks were either vanished or are less prominent due to the participation of the compliant of the functional group(s) in adsorption.

The absorption spectra of both surfaces (pure LC-fruit and LC-fruit on Figure 17-18, compared to the absence of the extract for fruit extract with the coupon in HCl and pipeline water, shows a peak at 3985-3746 indicated a strong and broad band indicating O-H stretching vibration.

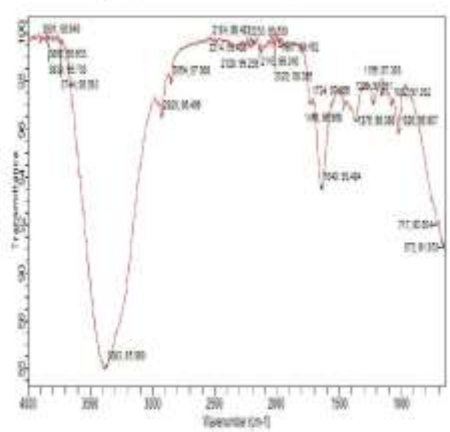

Fig.16: FTIR spectrum of pure *luffa cylindrica* extract

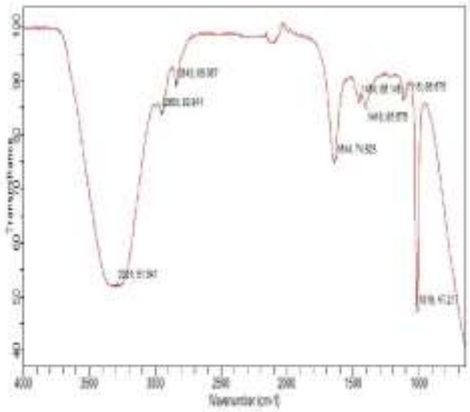

Fig. 17: FTIR spectrum of *Luffa* surface film after pipeline steel immersion in 0.5M HCl solution with *Luffa* extract.

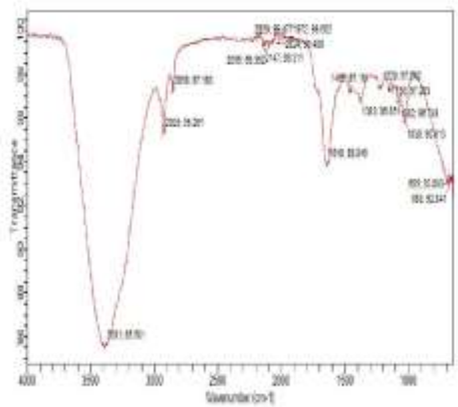

Fig. 18: FTIR spectrum of *Luffa* surface film after pipeline steel immersion in pipeline water solution with *Luffa* fruit extract.

A peak around 2939 O-H intermolecular bonded alcohol stretching mode. The peak at 2852 linked to stretching vibration of O=C=O. The band at 1979 indicated the presence of C-O, 1642 suggest C=C (alkene disubstituted), stretching frequency. The peak at 1378 confirmed OH stretch. The peak at 718 confirms C-H stretching (aromatic triple boded compound) while at 674 represent C-H stretching (aromatic compound).

*Conclusion***:** *Luffa cylindrica* fruit extracts was tested for inhibition of pipeline steel corrosion in acid solution and pipeline water. The results obtained showed good corrosion inhibition activity of the extract. The inhibition values increases with increasing concentration of fruit extract but decreased as the temperature increase.

DECLARATIONS

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 textto-image 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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