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CORROSION INHIBITION CHARACTERISTICS OF *PLUKENETIA CONOPHORA* SHELL EXTRACT ON CORROSION OF PIPELINE STEEL IN ACIDIC SOLUTION

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ABSTRACT

The ability of aqueous extract Plukenetia Conophora to inhibit pipeline steel corrosion in 0.5 M HCl acid was investigated using gravimetric and electrochemical techniques. Fourier transform infra-red spectroscopy (FT-IR technique) was used to study the corrosion surface film of the pipeline steel. The result shows that the corrosion rate decreased with increased extract concentration. The values from electrochemical impedance spectroscopy and weight loss measurement were consistent validating the inhibitory capacity of the extract. The Tafel plot revealed that the inhibitor acted as mixed class inhibitor. The FTIR spectra showed that the inhibitor molecules were deposited on the surface of electrode. The adsorption of inhibitor molecules on the steel surface was in accordance with the Temkin adsorption isotherm.

Keywords: Walnut shell, EIS, PDP, Corrosion, GC-MS.

INTRODUCTION

Metals are the bed rock of infrastructural development. However, acid corrosion of metallic structures has been a huge source of down turn for developed and developing economies. This is worsened by the fact the acidic solutions are used in many industrial operations, such as de-scaling and as cleaning agent (*Benabdellah et al*., 2006; Raja and Sethuraman 2008). Though corrosion is thermodynamically inevitable, it can be mitigated (*Brondel et al*., 1994). Corrosion has numerous negative consequences such as death, bad public images, and degraded ecosystem. However, it can be mitigated by corrosion inhibitors among other methods.

There are various techniques of corrosion mitigation. The use of green corrosion inhibitors are currently encouraged because of its high benefit to the ecosystem and renewability. Good sources of green inhibitors are plant extracts. These phyto resources contain phyto chemicals with hetro-atoms for adsorption on metallic surface (*Singh et al*., 2013; Rani and Selvaraj 2010). Many plant extracts had been previously used to inhibit corrosion of steel in acidic medium, this includes; *Zenthoxylum Alatium* (Chauhan and Gunasekaran 2007), *Andrographis Paniculata* (*Singh et al*., 2013), *Vitis Vinifera* (Rani and Selvaraj 2010), *Rosmarinus Officinalis* (Khalid and Salem 2011) etc.

Black African walnut shell or *Plukenetia Conophora* (PC) is also known as *Tetracarpidum Conophora* have a place within the group of Euphorbiacecae and is found in south west, south east Nigeria and Cameroun (Adeyemi *et al*., 2013). Plukenetia Conophora is a vital plant that is grown all through the temperate zones for its eatable nuts (Srinivasan and Viraraghavan 2008). It is also called Asukpa (Igbo) in the southern Nigeria, Awusa in the western Nigeria and Ngak in the western Cameroun. Plukenetia Conophora shells are waste produced in the Walnut harvest and preparation. According to Oliveira *et al*., 2008, walnut shell is regarded as a pollutant with little utility value. Hence, it is of almost interest to uncover suitable approaches for utilizing walnut shell. The shell of walnut seed was considered for research because it is cheap, renewable and the ground shell is easily biodegradable. Up till now, there is no existing literature on the use of aqueous PC shell extract or wall nut shell (WSE) as corrosion inhibitor in acidic medium. The motive of this study is to ascertain the effect of PC shell extract on the corrosion of steel pipeline in 0.5 M HCl acid solution by employing electrochemical and gravimetric techniques. Fourier Transform Infrared (FTIR) were used to study surface film of the study pipeline steel.

MATERIAL AND METHODS

Preparation of WSE

The *Plukenetia Conophora* nuts were bought from Choba market, Portharcourt, Nigeria, de-shelled. The shells were washed with distilled water to eliminate impurities and air-dried for 10 days. The dried plant samples were crushed and grounded using electrical blender until a fine powder was formed. The powder was sieved with a mesh size of 150 µm. Forty grams of ground *Plukenetia Conophora* shell was mixed with one litre of distilled water and then heated up at a temperature of 60^{o} C using a thermostatic water bath for 75 mins. The extract was allowed to cool and settle for 24 hours, afterwards it was filtered and the filtrate from the extract was evaporated to dryness at 40^{o} C. The corrosive solution was prepared by using 0.5 M HCL solution and *Plukenetia Conophora* shell extract (WSE) into various serial concentrations of 0.1 g/l, 0.2 g/l, 0.3 g/l, 0.4 g/l and 0.5 g/l WSE.

Fourier Transform Infra-red Spectroscopy

The FT-IR analysis was done for surface film of pipeline steel in 0.5 M HCl solution containing 0.5 g/L of aqueous WSE, after 24 hours immersion period. The adsorbed product of aqueous WSE was scrapped from the surface of steel pipeline, stir together with KBr and blend in a mortar. The mixtures was injected into a device and then compressed at a specified pressure thus creating a solid circular disk (*Oliveira et al*., 2008). This was completed by employing Buck scientific M530 USA FT-IR.

Electrochemical Methods

The electrochemical examinations were achieved by employing Princeton Applied Research Model 263A Potentiostat/Galvanostat. The pipeline steel coupons used for electrochemical measurement were square shape with the dimensions 1 cm × 1 cm. These coupons which are considered as working electrode were sealed with epoxy resin exposing only 1.0 cm^2 surface areas. The exposed layer is polished using various grades (200, 400, 600, 1200 and 1500) of emery papers, washed with distilled water, degreased in acetone and air- dried. This experiment was performed by using a conventional three electrode cell, where a saturated calomel electrode joined via luggin capillary served as reference electrode, a platinium foil act as counter electrode. Prior to measurement, the electrode was dipped in test solution at open circuit potential for 30 minute until a stable or steady state was achieved.

Potentiodynamic polarization measurements were obtained from - 0.15 v to + 0.15 vs Eocp with a scan rate of 0.2 Mv/s. The IE % was obtained using equation (1)

$$E.I(\%) = 100\left[1 - \frac{I\,bcorr}{Icorr}\right] \text{ .... } (1)$$

Where E.I (%) is percentage inhibition efficiency, I^b_{corr} represent corrosion current density without inhibitor and I^i_{corr} denotes corrosion density with inhibitor

The Electrochemical impedance spectroscopy (EIS) data were recorded from 10 kHz to 10 MHz with signal amplitude of 5 mV. All the analysis was done in triplicate to ensure reproducibility of data. Equation (2) was used to estimate the IE%

$$E.I_{EIS} = 100 \text{ X } \frac{(RctI - RctB)}{RctI} \text{ .... } (2)$$

Where RctB and RctI represent charge transfer resistance without and with the extract respectively.

Weight Loss Method

The pipeline steel coupons used for the weight loss method were mechanically cut in 3 cm x 2.5 cm x 1 cm dimensions. The composition of the pipeline steel has been previously reported by Ngobiri *et al.*, 2019. The coupons were polished repeatedly wit h various grades (200, 400, 600, 1200, 1500 and 2000) of emery paper until a smooth and shiny surface was achieved. The coupons were degreased in ethanol, cleansed with distilled water and rinsed in acetone and preserved in a desiccator to prevent interaction with the environment. The pre-weighed pipeline steel coupons were dipped in 100 ml of 0.5 M HCl acid solution without and with selected concentrations of WSE ranging from (0.1 g/l – 0.5 g/l) at temperatures of 303 K, 313 K and 323 K for 24 hours with the aid of a thermostatic water bath. After the exposure time, the coupons were withdrawn from the test solution, brushed, cleansed with distilled water, rinsed in acetone and air dried before taking final weight (*Robert et al.*, 2004). The inhibition efficiency and surface coverage were calculated by using equations 4 and 5 below (*Ogukwe et al.*, 2012).

$$\text{Weight Loss} = \Delta W_B - \Delta W_I \text{ ....} (3)$$

$$IE = \frac{\Delta W_B - \Delta W_I}{\Delta W_B} \times \frac{100}{1} \text{ .... } (4)$$

Where ΔW_B is weight loss of metal coupon without extract and ΔW_I is weight loss of metal with extract

$$\text{Surface Coverage} = \frac{\%IE}{100} \text{ .... } (5)$$

Corrosion Rates

The corrosion rates of coupons were studied in various test solutions at different temperatures using equation (8)

$$C_R = \frac{87.6\, X\Delta w}{DAT} \text{ .... } (6)$$

Where Δw is change in weight loss, D is density of coupon, A is area in centimeters and T is immersion time.

RESULTS AND DISCUSSIONS

Effects of aqueous WSE on corrosion of Steel pipeline in 0.5 M HCl

Table (1) indicates the effect of concentration of WSE on corrosion rate and inhibition efficiency at various temperatures. In the blank solution, corrosion rate was increasing as temperature was rising from 303 K to 323 K; but the introduction of aqueous WSE at selected concentrations caused a substantial decrease in corrosion rate of steel pipeline in 0.5 M acid solution; thus increasing inhibition efficiency owing to adsorption and large surface coverage of aqueous WSE molecules on steel pipeline surface (*Ogukwe et al.*, 2012). The optimum inhibition performance of 83.9 % and least corrosion rate of 0.00217 (mm py) was attained at 0.5 g/L concentration whereas the minimum in hibition efficiency was obtained at 0.1 g/L concentration. Furthermore, table 1 show that the inhibition performance of WSE decreased from 83.9 % at 303 K – 59.3 % at 323 K indicating a probable physio-sorption mode (*Ebenso et al.*, 2009).

Table 1: Corrosion rate and inhibition efficiency values obtained from weight loss measurement for Pipeline steel corrosion in 0.5 M HCl with and without aqueous WSE

	30^0 C		40^0 C		50^0 C	
Conentration	CRmmpy	IE_{WL} (%)	CRmmpy	IE_{WL} (%)	CRmmpy	IE (%)
0.5M HCl	0.01348	_	0.09548	_	0.17029	_
0.1g/L	0.00577	57.5	0.05956	37.5	0.11328	33.6
0.2g/L	0.00431	68.1	0.04942	48.0	0.09201	46.1
0.3g/L	0.00349	74.3	0.03815	59.9	0.08213	51.9
0.4g/L	0.00279	79.4	0.03474	63.3	0.07510	56.0
0.5g/L	0.00217	83.9	0.03153	66.5	0.06952	59.3

Kinetic Studies of aqueous WSE corrosion inhibition on pipeine steel in 0.5 M HCl.

The activation energy (Ea) values for the corrosion of steel pipeline in the 0.5M HCl solution without and with selected concentration aqueous WSE at varing temperatures was evaluated using equation 7. This equation describes the relationship between temperature and corrosion rate.

Figure (1) shows a linear plot of Log CR versus $(\frac{1}{T})$ with slope of $(\frac{-Ea}{2.303\ R})$. The activation energy value is gotten from the slope. Figure 1 and Table 2 shows that the obtained values of Ea were higher in solution containing aqueous WSE than the solution with no addictive. Also, the Ea values increased with increasing conce ntrations of aqueous WSE. According to E lmsellem *et al.*, 2014. This trend suggests that the molecules WSE of are physically adsorbed on steel pipeline. The same observations have been previously reported (Yadav *et al.*, 2010; Omotioma and Onukwuli, 2016).

This equation describes the relationship between temperature and corrosion rate.

$$\text{Log } C_R = \text{Log A} - \frac{Ea}{2.303RT} \text{ .... } (7)$$

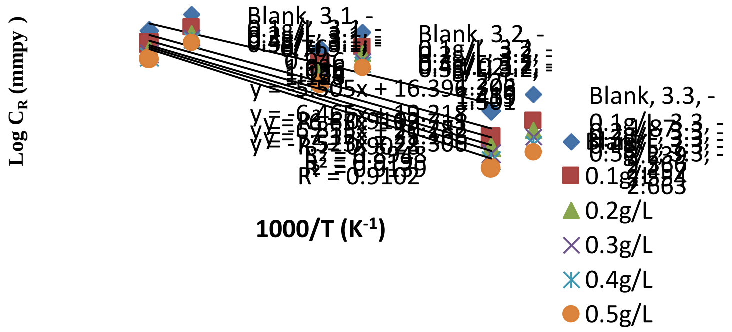

Figure 1: Linear plot of Log CR versus $(\frac{1}{T})$ for the corrosion of steel pipeline in the 0.5 M HCl solution without and with varying concentrations of aqueous WSE.

Table 2: Activation energy studies for adsorption of aqueous WSE on Pipeline steel in 0.5 M HCl

Concentration(g/L)	Ea(kJ mol^{-1})	R^2
Blank	105.40	0.9028
0.1	123.81	0.8945
0.2	127.33	0.9102
0.3	131.25	0.9109
0.4	136.90	0.9139
0.5	144.08	0.9102

Adsorption Isotherm

The understanding of corrosion inhibition characteristics of WSE will not be comprehensive without establishment of the adsorption mechanism that was responsible for the good inhibition performance. Adsorption isotherms have been used to predict adsorption of inhibitor molecules on metal surfaces and the adsorption mode. The values of surface coverage (θ) evaluated from the weight loss data were graphically fitted into the following adsorption isotherm; Langmuir, Temkins, El- Awady isotherm etc.

Temkin isotherm was preferred because of its good correlation constant. The mathematical illustration of Temkin isotherm is given below (Deyab, 2016).

$$\text{Exp } (-2a\ \theta) = KC \quad \text{.............. } (10)$$

the equation was expanded into

$$\theta = \frac{1}{-2a}\text{InC} + \frac{1}{-2a}\text{In K} \quad \text{.............. } (11)$$

Where θ means degree of surface coverage by aqueous WSE, (*a*) represents the molecular interaction between molecules, C is for concentration of WSE, K represents equilibrium constant. The molecular interaction (a) is classified by modes of interactions into positive value (+a) means force of attraction occurs between molecules of aqueous WSE and negative value (-) indicates force of repulsion occurs between molecules (*Deyab et al*., 2017).

Figure (2) shows a plot of θ against InC with slope $\frac{1}{-2a}$and intercept ($\frac{1}{-2a}$) .A straight line graph with a good correlation coefficient (r^2) close to unity was gotten, this confirms that the interaction between molecules of aqueous WSE and steel surface best fit temkins isotherm.

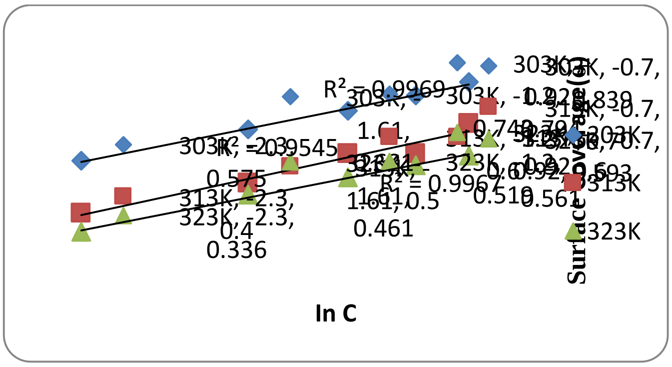

Figure 2: Temkins isotherm for the corrosion of pipeline steel in 0.5 M HCl solution without and with selected concentration of WSE at different temperatures.

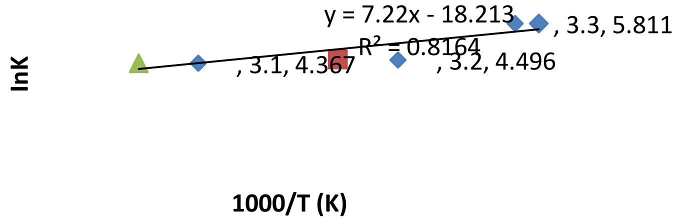

Figure 3: A plot of In K versus $\frac{1}{T}$ for the corrosion of pipeline steel in 0.5 M HCl solution without and with selected concentration of WSE.

From figure (2) the negative value of *a* confirms that repulsive force between molecules of aqueous WSE were accountable for the arrangement of films on steel surface. This observation was previously reported by *Li et al*., 2009. Also K_{ads} was observed to be decreasing with increasing temperatures meaning that molecules of WSE will undergo desorption as temperature change from 303 K - 323 K (*Li et al.*, 2008). In this current study, the estimated values of ΔG_{ads} at separate temperatures are slightly above 20 kJ mol^{-1}. According to Singh *et al.*, 2013, both physical and chemical adsorpti on may have occurred on the surface steel pipeline because the values of ΔG_{ads}

24.757 kJ mol^{-1}, 22.231 kJ mol^{-1} and 22.700 kJ mol^{-1} were slightly above 20 KJ mol^{-1} but less than 40 KJ mol^{-1}. Similar observations were previously reported (*Quartarone et al*., 2008; Karthik et al, 2015; Khadom *et al*., 2018). The negative values of ΔG_{ads} justifies that the adsorption of aqueous WSE on steel pipeline in 0.5 M HCl acid medium was spontaneous (Gadow and Motawea, 2017).

It can be deduced that K_{ads} may be related to ΔG using equation (12)

The values of ΔH_{ads} and ΔS_{ads} can be evaluated using Van Hoff equation.

$$\text{InK} = -\frac{\Delta Hads}{RT} + \text{Constant} \qquad \ldots\ldots\ldots (13)$$

A plot of Ink versus 1/T is found in figure (3) a straight line graph with slope ($-\frac{\Delta Hads}{R}$) was obtained. In order to calculate ΔH_{ads}, equation (14) was used

$$\Delta S_{ads} = \frac{\Delta Hads - \Delta Gads}{T} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

The calculated value of ΔH_{ads} is - 60.03 KJ mol^{-1} meaning that the adsorption process of aqueous WSE on steel pipeline was exothermic. According to *Singh et al.*, 2013, an adsorption process is classified as physisorption when the value of ΔH_{ads} is below 40 kJ mol $^{-1}$while chemisorption process point towards 100 kJ mol^{-1}. In the current work, the obtained value of ΔHads is yet again suggesting that both chemical and physical adsorption occ urred. Similar results have been reported by *Khadom et al.,* 2018. The values of ΔS_{ads} ranges from (-116.41 to 115.57). Generally, given that the adsorption of aqueous molecules of WSE on steel pipeline is exothermic, it should be associated with a decrease of entropy (Noor and Al-Moubaraki, 2008).

Electrochemical Studies for the Corrosion of Pipeline Steel in 0.5 M HCL solution without and with Selected Concentration of WSE.

Electrochemical impedance spectroscopy (EIS) studies for the corrosion of pipeline steel in 0.5 M HCl solution without and with selected concentration of WSE.

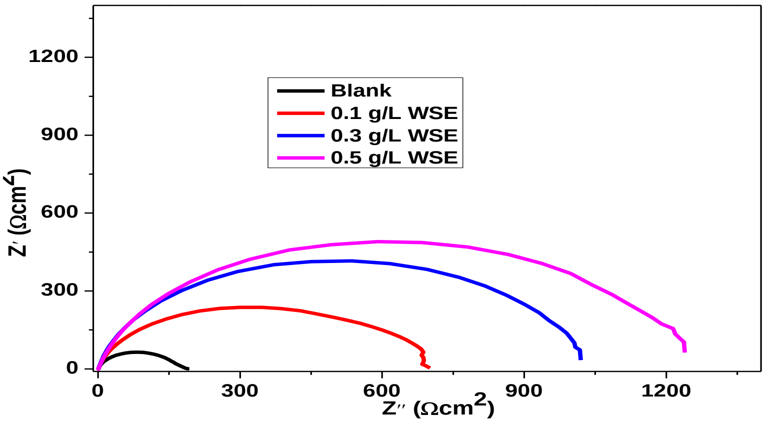

Figure 4: Nyguist plot for aqueous WSE for the corrosion of pipeline steel in 0.5 M HCl solution without and with selected concentration of WSE at different temperatures.

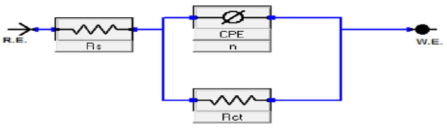

Figure 5: Electrical equivalent circuit model for the corrosion of pipeline steel in 0.5 M HCl solution without and with selected concentration of WSE at different temperatures.

The Nyguist plots for the corrosion of steel pipeline in 0.5 M HCl solution without and with selected concentrations of aqueous WSE at 303 K were displayed in figure (5), as the concentration of aqueous WSE increases; the diameter of the defective semicircles was increasing. This means a steady rise in concentration led to an increase in charge transfer resistance due to strong adsorption of inhibitor molecules of WSE at the metal-solution interface (Gadow, 2017). The obtained semicircular pattern suggests that corrosion of pipeline steel is primarily controlled by charge transfer process (*Ansari et al*., 2014). The information in table (6) shows that an increase in the concentration of aqueous WSE caused a decrease in the C_{dl} value from 169.9 μFcm^{-2} - 99.2 μFcm^{-2}; thereby, increasing inhibition performance. This decrease is primarily due to a reduction in the local dielectric constant or and an increase in the thickness of the double layer capacitance indicating that the molecules of aqueous WSE are strongly adsorbed at the metal- electrolyte interface (*Verma et al*., 2016).

The equivalent circuit presented in figure 5 was used to deduce the impedance data. This particular model consists of solution resistance (Rs), charge transfer resistance (Rct) and constant phase element (CPE). The CPE was employed in place of a capacitor due to imperfect, unevenness and defective nature of the electrode surface. The CPE can be described using the mathematical model below (Ahmed, 2006).

$$Z_{CPE} = Y_0^{-1} (Jw)^{-n} \text{ ....(15)}$$

Where Z_{CPE} = CPE impedance, Y_0 refers to CPE constant, w stands for angular frequency, $J = (-1)^{1/2}$ represents angular frequency and then n is used to describe the level of impurities, unevenness and irregularities on the surface of steel pipeline. The values of n represent the various function of CPE. The following values of n -1, 0, 0.5 and 1 are assigned to inductance, resistance, Warburg and capacitance.

The C_{dl} values were gotten from the equation below.

$$C_{dl} = (Y_o R_{ct}^{n-1})^{1/n} \text{ .... (16)}$$

In the current research, the values of n are below 1, hence, perfect capacitor was not achieved. This may be attributed to irregularity or coarseness on the surface of electrode (Gadow and Motawea, 2017). However, the value of n increased with increasing concentration of WSE indicating that the smoothness of the steel pipeline was greatly improved by adsorption of WSE inhibitor molecules. This conforms to results reported by *Keles et al*., 2015 and *Gupta et al*., 2016.

Table 3: EIS data for the corrosion of steel pipeline in 0.5 M HCl solution without and with selected concentrations of aqueous WSE

	Blank	0.1 WSE	0.3 WSE	0.5 WSE
R_s (Ωcm^2)	1.02	1.13	1.15	1.19
R_{ct} (Ωcm^2)	192.2	701.6	1019.5	1239.1
Y_o ($\Omega^{-1} s^n cm^{-1}$)	201.8	135.8	166.3	176.4
α ($x10^{-3}$)	877.5	889.3	891.4	889.6
Fit ($x10^{-3}$)	12.4	86.2	13.5	14.2
n	0.792	0.809	0.814	0.833
C_{dl}($\mu F cm^{-2}$)	169.6	138.2	120.7	99.2
$\mathcal{E}_{EIS}$ (%)	-	72.6	81.1	84.5

Table 4: Thermodynamic parameters for WSE corrosion inhibition for Pipeline steel in 0.5 M HCl.

Temperature	*A*	$\ln K_{ads}$	ΔG_{ads} kJ/mol^{-1}	ΔH_{ads}kJ/mol^{-1}	ΔS_{ads} (J/mol /k)	R^2
303K	-3.073	5.811	-24.757	-60.03	-116.41	0.9969
313K	-2.839	4.526	-22.231	-60.03	-120.76	0.9545
323K	-3.129	4.437	-22.700	-60.03	-115.57	0.9967

Potentiodynamic Polarisation (PDP) Studies for corrosion inhibition by aqueous WSE on pipeline steel in 0.5 M HCl

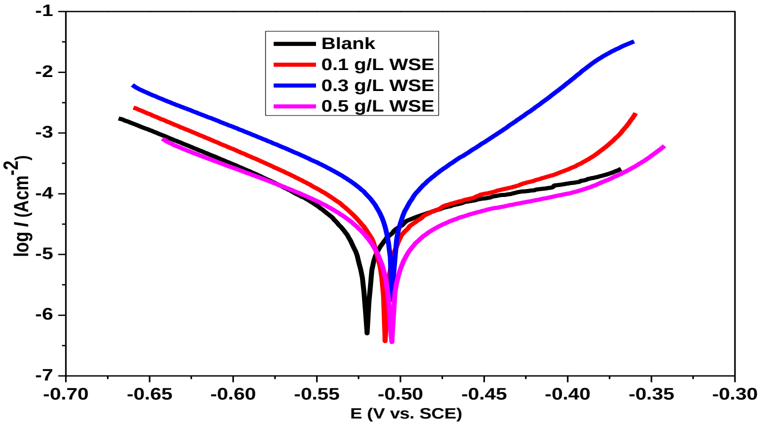

Figure 6: Tafel plot for the corrosion of pipeline steel in 0.5 M HCl solution without and with selected concentration of WSE.

Table 5: PDP Parameters for aqueous WSE corrosion inhibition by aqueous WSE on pipeline steel in 0.5 M HCl

Parameters	Blank	0.1 WSE	0.3 WSE	0.5 WSE
β_a(mV/decade)	84.4	88.1	92.9	99.6
β_c(mV/decade)	93.7	84.3	88.6	87.4
I_{corr} (μAcm^{-2})	611.8	164.5	113.5	82.3
E_{corr} (mV)	-529	-510	-509	-503
ε_{PDP} (%)	-	73.1	81.5	86.6

The different tafel plots parameters for anticorrosion properties of aqueous WSE in 0.5 M HCl acid at 303 K is shown in table 5 and figure (6). It was observed that as concentration of aqueous WSE is increasing the corrosion density (I_{corr}) significantly reduced. This trend justifies the anticorrosion properties of aqueous WSE in acidic medium. Also, the addition of aqueous WSE influences the tafel constants by increasing the values of βa but the values of βc was partial reduced in the presence of addictive compared to the solution with no extract. As a result, the βa values were found to be higher than the βc values insinuating that WSE functioned as mixed type inhibitor with anodic predominance. *Ngobiri et al*., 2019 had earlier observed similar trend. The difference between E_{corr} values for the solution with no addictive and that containing selected concentration of WSE is below 85 mV; hence, aqueous WSE is classified as a mixed-type inhibitor (*Solomon et al*., 2017). The fact that the E_{corr} values were shifting towards the positive direction is yet again highlighting that the anodic reaction was largely controlled (Hussin and Kassim, 2011). The inhibition efficiency increased with increase in concentration of aqueous WSE. This trend is similar to the results obtained from weight loss and electrochemical impedance method.

FT-IR STUDIES OF WSE

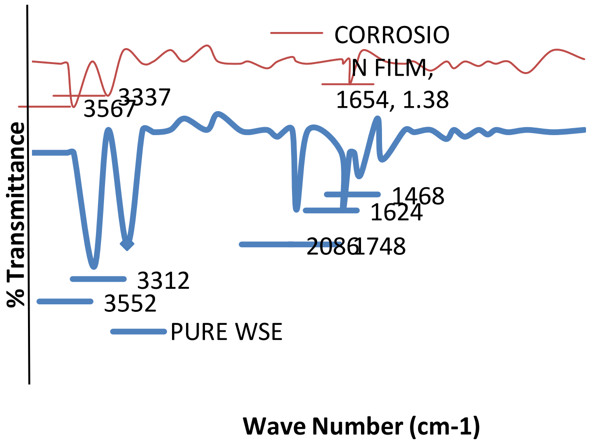

Figure 7: FT-IR of surface film of WSE for the corrosion of pipeline steel in 0.5 M HCl solution.

The crude WSE shows the presence of various functional groups. Peaks ranging from 3552 cm^{-1} to 3312 cm^{-1}may be attributed to the presence of O-H (Alcohol) and carboxylic acid stretching frequency. The bands at 2086 cm^{-1}, 1748 cm^{-1}, 1624 cm^{-1} and 1468 $\mathbf{cm^{-1}}$ may be attributed to the functional groups below C≡C, C=O (Aldehyde), C=O (Cabo xylic Acid), C-H (Alkane). After comparing the FT-IR spectre of pure WSE with the FT-IR spectra of its adsorbed protective film deposited on pipeline steel surface after immersion in 0.5 M HCl containing 0.5 g/L WSE it was noted that new peaks appeared, some disappeared while other shifted to higher wave frequency. The following peaks shifted from 3552 to 3567 cm^{-1}, 3312 to 3337 cm^{-1}, 1624 to 1654 cm^{-1}. While 2086 cm^{-1}, 1748 $cm^{-1}$and 1468 cm^{-1}disappeared. This trend confirmed the interaction between inhibitor molecule and Fe^{+2} on pipeline steel (Philippe and Florian, 2006; Omotioma, and Onukwuli, 2016).

Inhibition Mechanism

The results gathered from EIS showed the presence of surface film while the FTIR results also confirms the adsorption of OH, C=O, COOH and alkyne groups on the pipeline steel surface. These functional groups contain polar atoms that have pi and lone pairs of electrons, which can function as adsorption site on the surface of electrode. The information from polarization result revealed that both anodic and cathodic reactions were effectively controlled due to the presence of aqueous WSE. Firstly, these phytochemicals containing oxygen atoms were protonated by protonating agent present in the acid solution. The protonated molecules reduce the rate of hydrogen evolution at the cathodic area of the electrode; it is also possible that adsorption occurred at the anodic area of the electrode due to the interaction between metal and lone pairs of electron from O atom and Pi electrons from alkyne group, consequentially reducing the dissolution of the metal (Mourya et al., 2014).

CONCLUSION

The corrosion inhibition characteristics of aqueous WSE were studied by using electrochemical and gravimetric techniques. While the corrosion surface characteristics were studied using FT-IR. An inhibition efficiency of 83.9 % at 303 k was recorded due to the presence of aqueous WSE. The tafel plots confirmed that aqueous WSE inhibited both anodic and cathodic reaction at the surface of electrode. Hence, WSE behaved as mixed type corrosion inhibitor. However, the efficiency decreased at 323 k due to the influence of temperature, characteristic of physisorption. The adsorption process was recorded to be orderly, spontaneous and exothermic. FTIR spectra confirm that molecules of aqueous WSE are adsorbed on the surface of electrode. The molecules of aqueous WSE adsorbed on the surface of pipeline steel in 0.5 M HCl solution agrees with Temkins isotherm. While the free energy values of WSE suggests that both chemisorption and physisorption occurred on the surface of steel pipeline.

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