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Phytochemical constituents of *Taraxacum officinale* leaves as eco-friendly and nontoxic organic inhibitors for stainless steel corrosion in 0.2 M HCl acid medium

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Abstract
Taraxacum officinale leaves were extracted of its phytochemical compounds (crude saponins, flavonoids and alkaloids) and used in the investigation of corrosion inhibitor of stainless steel in the presence of HCl acid solutions using methods ranging from weight loss, thermometric, potentiodynamic polarization and electrochemical impedance spectroscopy. The weight loss results revealed that the plant extracts are good corrosion inhibitors to the exposed metal. Electrochemical polarization data revealed a mixed mode of inhibition and the results of electrochemical impedance spectroscopy have shown that the change in the impedance parameter (charge transfer resistance and double layer capacitance) with the change in concentration of the inhibitors was due to the adsorption of active molecules leading to the formation of a protective layer on the surface of steel. A physical adsorption mechanism was revealed from the inhibitor /metal interface and the Langmuir adsorption isotherm was well obeyed ($R^2 = 0.999$). The thermodynamic parameter (ΔG_{ads}) proved inhibitors to be stabled on the metal surface and a spontaneous reaction process was recorded also.

Keywords: inhibition, weight loss, impedance, polarization, adsorption, alkaloids

1. Introduction
Corrosion can be viewed as the degradation of a material due to a reaction with its environment [1-5]. This implies deterioration of physical properties of the material. This can be a weakening of the material due to a loss of a cross sectional area, it can be the shattering of a metal due to hydrogen embrittlement, or it can be the cracking of a polymer due to sunlight exposure [1–3]. The consequences of corrosion are many and varied and the effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than the simple loss of a mass of metal. Failure of various kinds and the need for expensive replacement may occur even though the amount of metal destroyed is quite small. In order to reduce the corrosion of metals, the application of inhibitors is one of the best methods of preventing metals against corrosion [4-6]. It has been found that most corrosion inhibitors are organic compounds containing polar fractions with nitrogen, sulphur or oxygen in the conjugated system that severely inhibit the corrosion of metals especially steel, aluminium, copper, etc. in acidic and alkaline environments [2-3]. Use of inhibitors is one of the most practical methods for protection against corrosion especially in acid solutions to prevent unexpected metal dissolution and acid consumption. Copper corrosion protection has become important particularly in acid media because of the increased industrial applications of acid solutions. The known hazardous effect of most synthetic corrosion inhibitors is the motivation for the use of some natural products. The use of chemical inhibitors has been limited because of the environmental threat and also in recent times due to environmental regulations [7-8].

Taraxacum officinale (Dandelion) is edible flowering plants. The flowers, stem and leaves are also used in production of a number of medicines. It is a rich source of vitamins and nutrients and also used to make wine and coffee substitutes. In the clinical investigation of this plat potentilas, it has been found that the plant can cure liver issues, act as a cleaning tonic for blood vessels, balance blood suger level and cholesterol level, prevent against gallstones, etc. in food, the plant is used as salad greens, and in soups, wine and teas while the roasted root is used as a coffee substitute. Aside the fact that the leaves contain significantly more protein, fats, and crude fibre, they also contain more phosphorus, potassium, calcium, iron and zinc [9].

The chief constituent of *Taraxacum officinale* (Dandelion) is Taraxacin, (an acrid resin, with ilunin, gluten, gum and potash) and acrystalline (Figure 1). Research also shows the presence of tocopherols, thiamine, riboflavin, niacin and L – ascorbic acid [9].

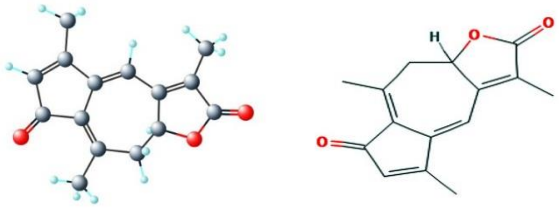


Fig 1: Taraxacin (trimethyl-3a,4-dihydroazuleno[6,5-b]furan-2,6-dione, $C_{15}H_{14}O_3$)

The use of this plant especially its phytochemical constituents in the area of corrosion and electrochemistry has been very scanty, the reason that inform the researchers decision to try the phytochemical constituents of the leaves of the plant in the corrosion and electrochemical study of stainless steel in hydrochloric acid medium.

2. Experimentation

2.1 Preparation of Samples

The stainless steel sheet was press cut into coupons of dimensions 2.0 cm x 2.0 cm x 0.08 cm for chemical (weight loss and thermometric) and 1 cm x 1 cm for electrochemical (impedance and potentiodynamic polarization) measurements respectively. The coupons were polished using successive grades of silicon carbide paper, then degreased in ethanol to remove the surface dirt arising from the abraded process, rinsed with acetone and air dried. The prepared metal substrates were stored in a desiccator prior to use.

Meanwhile the fresh leaves of *Taraxacum officinale* obtained from in Northern Cross River state, Nigeria were washed and cut into small pieces, then dried in oven at 60^0C, followed by grinding to obtain a powdered sample with very fine particle size. The powdered sample was extracted in absolute ethanol using soxhlet extraction process. The crude leave extract and solvent was placed in a water bath for 5 hours to evaporate the solvent leaving a paste for alkaloids and saponins extraction.

2.2 Preparation of crude saponins, flavonoids and alkaloids inhibitor solutions

For the crude alkaloid fraction, 80 g of the crude ethanol extract was partitioned between 200 ml of chloroform and 0.5 M HCl solution respectively using a separating funnel. The HCl solution in the float fraction from the separating funnel was carefully basify with 300 ml ammonia solution and this was taken well above pH 7. 300 ml of chloroform was immediately added into the basic solution in the separating funnel to obtain two immiscible layers with the lower one containing the alkaloids. The chloroform layer was eventually separated from mixture and put aside, the chloroform distilled off, and a small quantity of the crude alkaloids was obtained.

Meanwhile, crude saponins extracts was prepared by heating 50 g of crude *Taraxacum officinale* leaves extract in 20 ml of methanol for 5 hours using a water bath, followed by addition of 25 ml of chloroform to separate organic portion from the aqueous. The organic fraction was discarded while methanolic fraction was then diluted with 10 ml butanol. Both mixtures were then separated to dryness to obtain a crystalline soapy extract used as crude saponins.

In another experiment, 100 g of the dried powdered sample was weighed into a beaker and extracted with 100 ml of ethanol at room temperature for 1 hour. The solution was filtered and the filtrate was evaporated to dryness over water bath at 50^0 C. The weight of the dried extract was taken and the amount of flavonoid present was calculated.

5 g each of both the crude saponins, flavonoids and alkaloids extracts were separately soaked in 1000 ml of HCl solution and kept for 1 day. The solutions obtained were filtered and stored. From the stock solution, inhibitor test solution of concentrations 0.1 g/L, 0.3 g/L, 0.7 g/L, 1.5 g/L and 3.0 g/L was prepared. The prepared solutions were then used to study the corrosion inhibition impact of the phytochemical compounds.

2.3 Weight loss method

Gravimetric (weight loss) experiment was carried out to study the effect of addition of different concentrations (0.1 g/L, 0.3 g/L, 0.7 g/L, 1.5 g/L and 3.0 g/L) of phytochemical components of crude *Taraxacum officinale* on stainless steel corrosion in 0.2 M HCl.The polished metals were initially weighed and immersed in 100 ml test solution for 1 hour in the absence and presence of various concentrations of inhibitor at room temperature. After immersion time the metals were picked out, cleaned with distilled water, rinsed with ethanol and degreased with acetone and immediately aid dried. The specimens were again weighed using electronic balance (sensitivity up to 4 d.p). The corrosion rate (R_c) of inhibitor (in $mgcm^{-2}\ h^{-1}$) was obtained graphically from a plot of weight loss against time. Inhibition efficiency (%IE) of inhibitor was calculated from equation 1.

$$IE\% = \left(\frac{R_o - R_i}{R_o} \right) x100$$

Where

R_o and R_i are the corrosion rates in the absence and presence of the plant extracts.

2.4 Thermometric measurements

Hundred ml of the 0.2 M HCl was emptied into a beaker. Thereafter, a stainless steel metal of dimension 2.0cm x 2.0 cm x 0.08 cm already weighed was dropped into the 0.2 M HCl and the beaker immersed in a water bath. The volume of the hydrogen gas evolved from the corrosion reaction was regulated by temperature changes in the water bath. After every 1 hour at different temperatures of 298 K, 313 K and 333 K, the metal was removed, degreased with ethanol, rinsed with acetone and air dried and then weighed. This procedure was repeated for a set of fresh coupons at different concentrations (0.1 g/L, 0.3 g/L, 0.7 g/L, 1.5 g/L and 3.0 g/L) of crude *Taraxacum officinale* extracts.

2.5 Electrochemical determination

Stainless steel coupons (1 cm x 1 cm), graphite rod and silver/silver chloride (Ag/AgCl) were used as working, counter and reference electrodes, respectively for the electrochemical measurements. All the measurements were taken after the working electrode was immersed for 30 minutes in the different test solutions at room temperature in order to attain a steady-state open-circuit potential (OCP). The frequency range from 100 kHz to 0.01 Hz with amplitude of 10 mV was used in electrochemical impedance experiments. The potentiodynamic polarization curves were recorded from cathodic potential of -100 mV to anodic potential of +100 mV at a scan rate of 0.5 mV $s^{-}1$ with respect to free corrosion potential (E_{corr}). The linear Tafel segments of the anodic and cathodic curves were extrapolated to corrosion potential to obtain the corrosion current densities (icorr) and other electrochemical parameters of interest. Inhibition efficiency from electrochemical impedance spectroscopy (EIS), and

potentiodynamic polarization (PDP) was computed using Eqs (2) and (3) respectively.

$$IE_{EIS} = 1 - \left(\frac{R^0_{ct}}{R_{ct}}\right) x\ 100 \quad \ldots\ldots\ldots (2)$$

Where
R^0_{ct} and R_{ct} are the charge transfer resistances in the absence and presence of the inhibitors respectively.

$$IE_{PDP} = 1 - \left(\frac{i_{corr}}{i^0_{corr}}\right) x\ 100 \quad \ldots\ldots\ldots\ldots (3)$$

Where
i^0_{corr} and i_{corr} are the corrosion current densities in the absence and presence of inhibitor respectively.

3. Result

3.1 Evaluation of gravimetric analysis data

The weight loss expressed as the corrosion rate for the copper coupons in 0.2 M HCl solutions containing different concentrations of crude alkaloid, flavonoid and saponins extracts of *Taraxacum officinale* as a function of inhibitor concentration is presented in Table 1. It is observed that the corrosion rates decreased with increase in concentration of both extracts (Figure 3), indicating that the extent of inhibition is dependent upon the amount of extract present [5, 7-10]. Also from Table 1, it is observed that the inhibition efficiencies increase with increase in extracts concentration (Figure 2). This indicates that the phytochemical components of the extracts are adsorbed onto the metal surface resulting in the blocking of the reaction sites, and protection of the steel surface from the attack of the acid [11-15].

Table 1: Gravimetric analysis values for corrosion rate, surface coverage and inhibition efficiency for stainless steel corrosion by phytochemical constituents of *Taraxacum officinale* in 0.2 M HCl medium

	SETOL			FETOL			AETOL		
Conc. (g/L)	**CR (mg/cm2/h)**	**θ**	**%IE**	**CR (mg/cm2/h)**	**θ**	**%IE**	**CR (mg/cm2/h)**	**θ**	**%IE**
0.2 M HCl	0.682	-	-	0.682	-	-	0.682	-	-
0.1 g/L	0.314	0.540	54.0	0.237	0.652	65.2	0.174	0.745	**74.5**
0.3 g/L	0.257	0.623	62.3	0.149	0.782	78.2	0.104	0.848	**84.8**
0.7 g/L	0.099	0.855	85.5	0.084	0.877	87.7	0.068	0.900	**90.0**
1.5 g/L	0.062	0.909	90.9	0.038	0.944	94.4	0.016	0.977	**97.7**
3.0 g/L	0.021	0.969	96.9	0.012	0.982	98.2	0.005	0.993	**99.3**

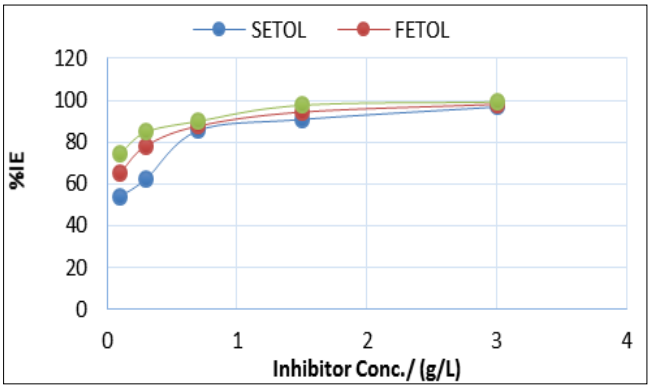


Fig 2: Variation of inhibition efficiency of the inhibitors with concentrations for the corrosion of stainless steel in 0.2 M HCl solution

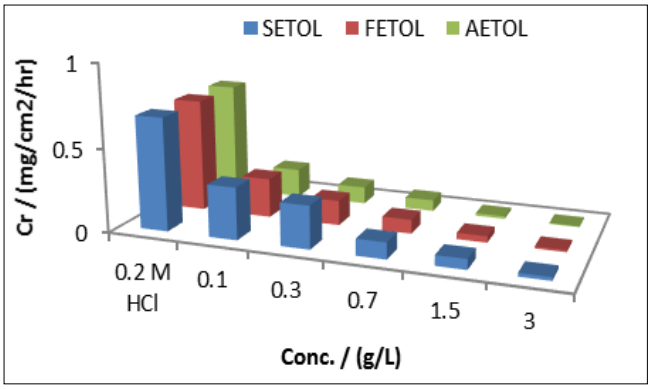


Fig 3: Variation of corrosion rate of metal with inhibitor concentrations for the corrosion of stainless steel in 0.2 M HCl solution

3.2 Evaluation of thermometric data

The influence of temperature on the corrosion inhibitive behavior of the tested inhibitors was investigated from the thermometric method data in the temperature range of 298, 313 and 333 K (Figures 3a – c and 4a – c). Results obtained as shown in Table 2 revealed that corrosion rate increased with increase in temperature in the absence and presence of the inhibitors but decreased with increased inhibitor concentration. On the other hand, inhibition efficiency of the inhibitors decreased as temperature was increased and increase with inhibitor concentration. The apparent decrease in inhibition efficiency (%) as temperature was raised from 298, 313 and 333 K for all phytochemical compounds could be related to change of adsorption mode from chemisorption to physisorption caused by desorption of adsorbed inhibitor as a result of increased solution agitation due to higher rate of hydrogen gas evolution [6, 9, 12]. This is verified from the higher values of inhibition efficiency noticed at the lowest temperature (298 K) against the highest (333 K).

Table 2: Thermometric analysis values for corrosion rate, surface coverage and inhibition efficiency for stainless steel corrosion by phytochemical constituents of *Taraxacum officinale* in 0.2 M HCl medium

		CR (mg/cm2/h)			θ			% IE		
	Conc. (g/L)	298K	313K	333K	298K	313K	333K	298K	313K	333K
	Blank	0.492	1.953	6.654	-	-	-	-	-	-
SETOL	0.1 g/L	0.265	1.136	4.496	0.461	0.418	0.324	46.1	41.8	32.4
	0.3 g/L	0.236	1.074	4.237	0.520	0.450	0.363	52.0	45.0	36.3
	0.7 g/L	0.207	0.891	3.085	0.579	0.544	0.536	57.9	54.4	53.6
	1.5 g/L	0.057	0.533	2.571	0.884	0.727	0.614	88.4	72.7	61.4
	3.0 g/L	0.046	0.277	1.892	0.907	0.858	0.716	90.7	85.8	71.6
FETOL	Blank	0.492	1.953	6.654	-	-	-	-	-	-
	0.1 g/L	0.223	0.966	3.877	0.547	0.505	0.417	54.7	50.5	41.7
	0.3 g/L	0.210	0.731	3.142	0.573	0.626	0.528	57.3	62.6	52.8
	0.7 g/L	0.097	0.591	2.829	0.803	0.697	0.575	80.3	69.7	57.5
	1.5 g/L	0.042	0.369	2.160	0.915	0.811	0.675	91.5	81.1	67.5
	3.0 g/L	0.027	0.141	1.456	0.945	0.928	0.781	94.5	92.8	78.1
AETOL	Blank	0.492	1.953	6.654	-	-	-	-	-	-
	0.1 g/L	0.216	0.873	3.694	0.561	0.553	0.445	56.1	55.3	44.5
	0.3 g/L	0.183	0.632	2.961	0.628	0.676	0.555	62.8	67.6	55.5
	0.7 g/L	0.072	0.419	2.514	0.854	0.785	0.622	85.4	78.5	62.2
	1.5 g/L	0.025	0.266	1.867	0.949	0.864	0.719	94.9	86.4	71.9
	3.0 g/L	0.009	0.096	1.015	0.982	0.951	0.847	98.2	95.1	84.7

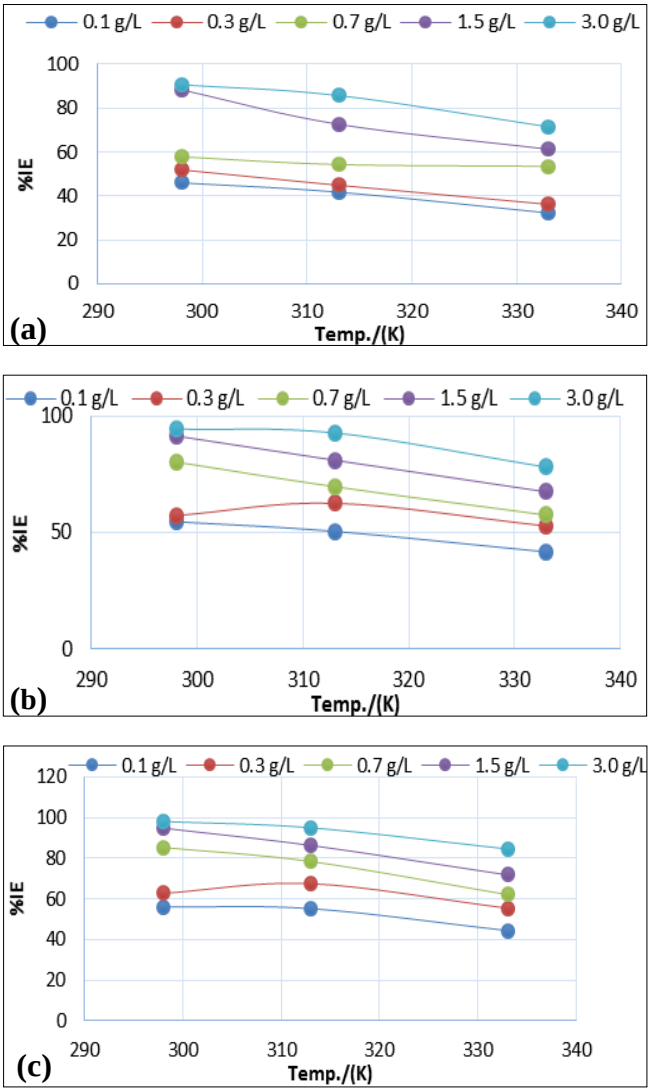


Fig 3: Plot of %IE against Temperature (K) for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

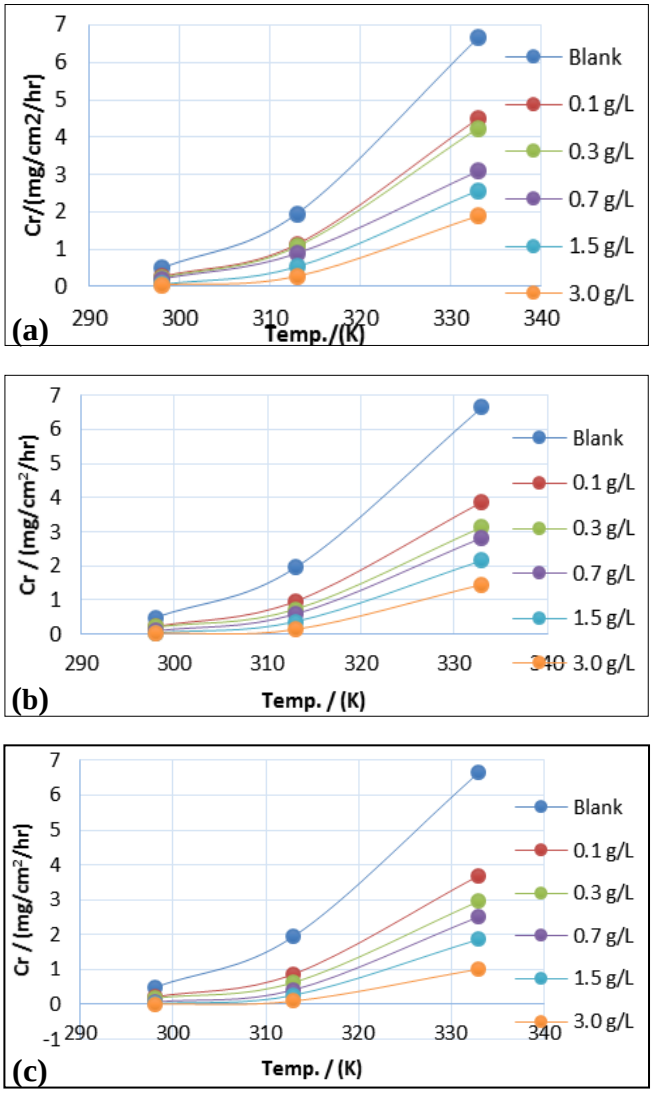


Fig 4: Plot of corrosion rate against Temperature (K) for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

3.3 Evaluation of electrochemical impedance data

Fig. 5a-c xtended semicircle in the complex impedance plane both in uninhibited and inhibited solutions, an indication that corrosion rate is controlled by charge transfer resistance [13-15]. The impedance diagrams obtained increases in diameter as inhibitor concentration increases indicating that the presence of inhibitor molecules strengthens the inhibitive film occurring through defects of this film with increase in *Symphytum officinali* concentration [9, 13]. Table 3 shows that C_{dl} values decreased when the concentration of the inhibitor molecules increased. The decrease in C_{dl} might arise from a decrease in local dielectric constant and/or an increase of the electrical double layer thickness which might arise from substitution of preadsorbed water molecules on the metal/electrolyte interface by adsorbed organic constituents of *Symphytum officinali* extract, suggesting that inhibitor molecules function by adsorption at the metal/solution interface [14].

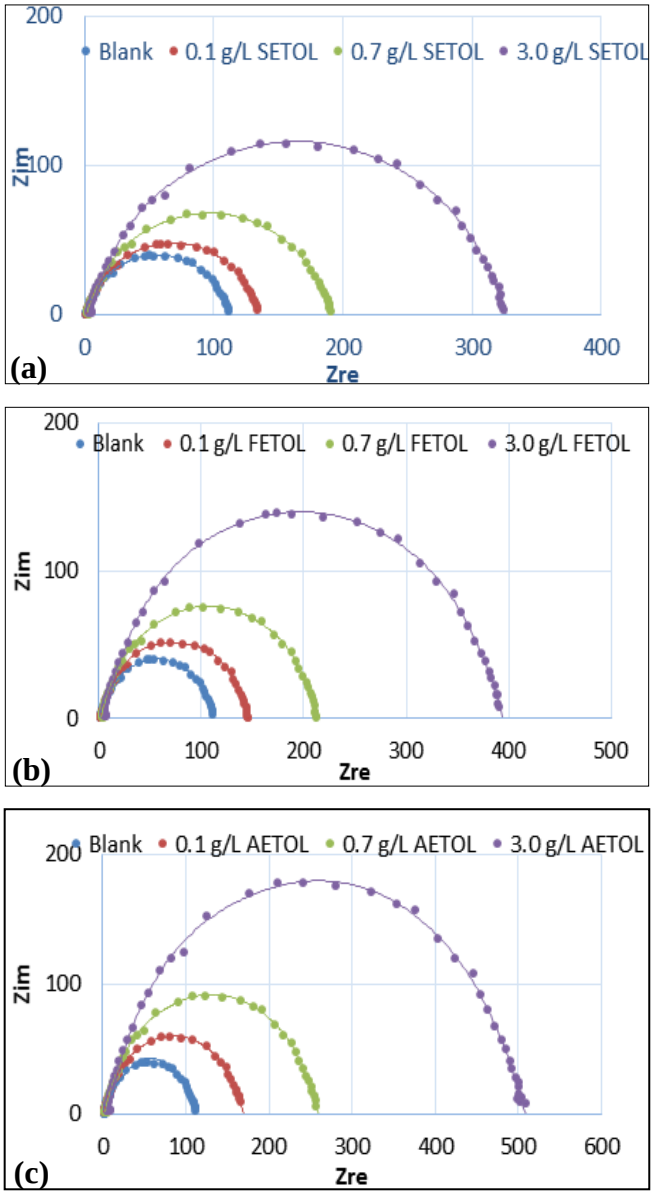


Fig 5: Nyquist plots for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

Table 3: Electrochemical Impedance spectroscopic data for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

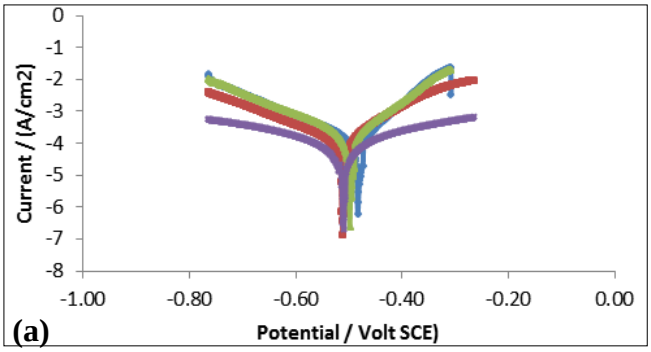
	Conc. (g/L)	R_{ct} (Ωcm_{-2})	C_{dl} (μFcm^{-2})	IE %
	Blank (1 M HCl)	**106**	**5.1 x 10^{-3}**	-
SETOL	0.1 g/L	143	1.6 x 10^{-3}	25.9
	0.7 g/L	198	7.9 x 10^{-4}	46.5
	3.0 g/L	345	4.5 x 10^{-4}	69.3
FETOL	0.1 g/L	147	3.8 x 10^{-3}	27.9
	0.7 g/L	210	2.0 x 10^{-3}	49.5
	3.0 g/L	397	1.1 x 10^{-3}	73.3
AETOL	0.1 g/L	191	4.7 x 10^{-3}	44.5
	0.7 g/L	276	3.9 x 10^{-3}	61.6
	3.0 g/L	504	1.9 x 10^{-3}	79.0

3.4 Evaluation of Potentiodynamic polarization data

The polarization behaviour of stainless steel electrodes in 0.2 M HCl solutions with and without the different concentrations of saponins, flavonoids and alkaloid extracts of *Taraxacum officinale* leaves are shown in Fig. 6a - c. The polarization curves show that in presence of the extracts of *Taraxacum officinale* leaves the cathodic and anodic branches of the polarization curves are shifted towards lower currents, probably due to the consequence of the blocking effect of the adsorbed inhibitor molecules [15–16]. As it can be observed from Table 4, the anodic and cathodic reactions are affected by the inhibitors implying that the addition of the inhibitors reduces the anodic dissolution of the steel and also retards the cathodic hydrogen evolution reactions. The inhibitive action of these inhibitors on stainless steel metal therefore may be related to its adsorption and formation of a barrier film on the electrode surface, protecting them from corrosion [12].

Table 4: Potentiodynamic polarization data for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

	Conc. (g/L)	Icorr (mAcm-2)	βc (mV/dec)	βa (mV/dec)	IE (%)
	Blank (1 M HCl)	0.141	99	111	-
AETOL	0.1 g/L	0.066	84	92	53.2
	0.7 g/L	0.043	71	84	69.5
	3.0 g/L	0.027	55	63	91.5
FETOL	0.1 g/L	0.079	80	76	44.0
	0.7 g/L	0.051	61	71	63.8
	3.0 g/L	0.031	41	55	78.0
SETOL	0.1 g/L	0.097	73	67	31.2
	0.7 g/L	0.062	52	40	56.1
	3.0 g/L	0.039	37	34	72.3



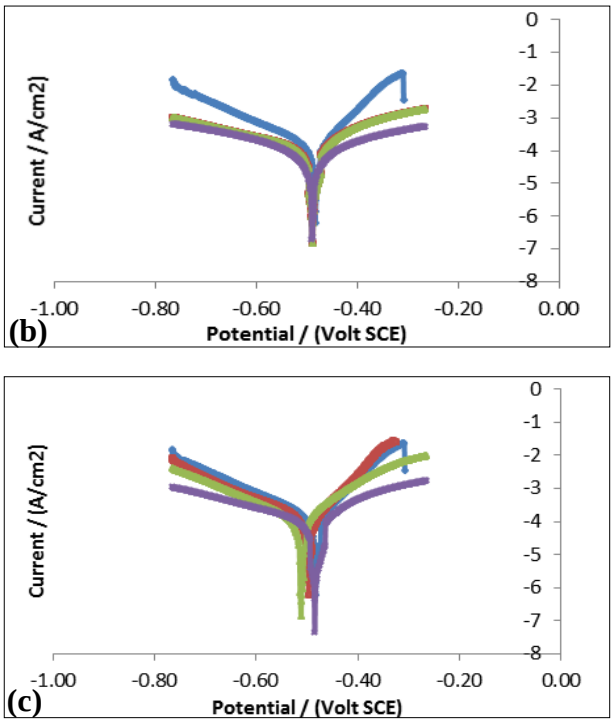


Fig 6: Tafel plots for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

3.4 Evaluation of thermodynamic data

The temperature of the system was varied across the inhibitor concentrations from which the activation energy for the corrosion of stainless steel in solutions of 0.2 M HCl was evaluated using the Arrhenius equation given by equation4

$$\ln R_c = \ln A - \frac{E_o}{RT} \quad (4)$$

Where Rc is the corrosion rate, Ea is the apparent effective activation energy, R is the general gas constant, and A is the Arrhenius pre-exponential factor. Calculated values of activation energy were obtained from the slope of Fig. 7a – c and presented in Table 5. The values obtained are higher than the value obtained for the blank, an indication that saponins, flavonoids and alkaloid extracts of *Taraxacum officinale* retards the corrosion of copper in 0.2 M HCl solutions [18]. Since the activation energy which is the energy required to oxidize metal is increased with inhibitor concentration, it implies that more energy has to be supplied to the system for the corrosion to take place, thus the observed decrease in corrosion rate. The values are also consistent with the data expected for the mechanism of physical adsorption (<80KJmol^{-1}). However, a slow electron transfer has high activation energy and if such a reaction is to proceed at a reasonable rate and produce an efficient quantity of corrosion product, a significant increase of applied potential over the equilibrium value is necessary. This excess potential will however result in an activation polarization. Thus the slow determining step at the high activation energy state in the process is the electron transfer due to high activation energy barrier which it must overcome (Atkins and Paula, 2002) In other words, the adsorption of the inhibitor on the electrode surface leads to the formation of a physical barrier that reduces the metal activity in the electrochemical reactions of the corrosion

Thermodynamic parameters were calculated using equation 5 (transition state equation), which can be written [13, 19].

$$\frac{CR}{T} = log\left[\frac{R}{Nh} + \frac{\Delta S}{2.303R} - \frac{\Delta H}{2.303RT}\right] \quad (5)$$

From equation 5, values of log (C_R/T) were plotted against 1/T as shown in Fig. 8a - c and from the slope and intercept of the plots, values of enthalpy and entropy of adsorption were calculated as shown in Table 5. From the calculated values of ΔH_{ads}, it can be deduced that the adsorption of the inhibitor on steel surface is endothermic [11, 20]. The negative values for ΔS_{ads} shows the non-spontaneous dissolution of the metal and the increase in its value suggests decrease in disordering in the rate determining step, hence increase stability of inhibitors on steel surface [21].

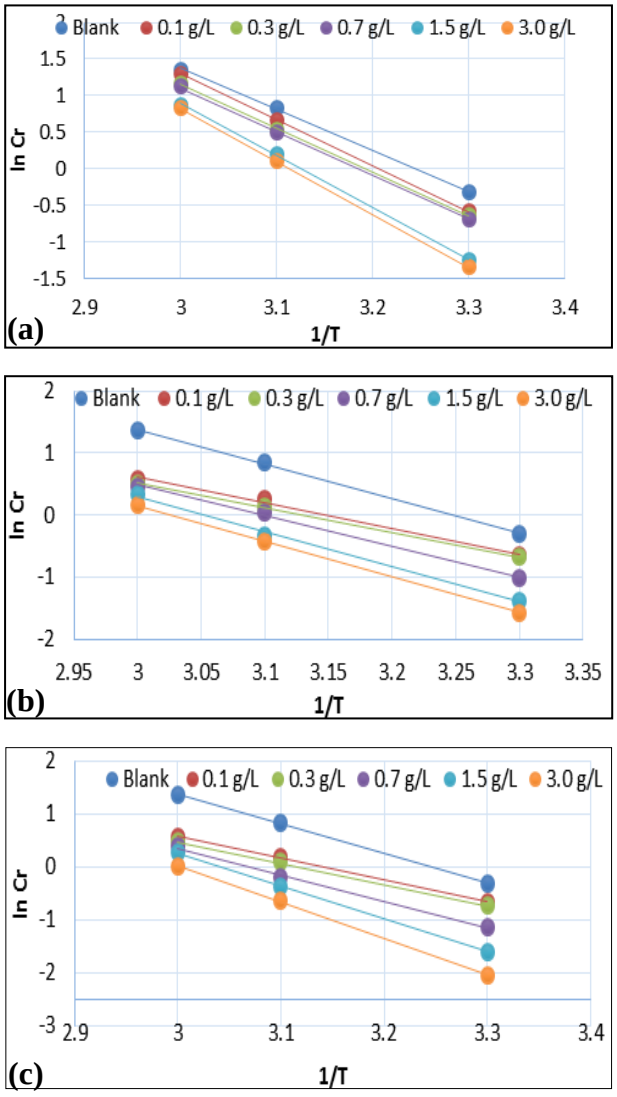


Fig 7: Arrhenius plots for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

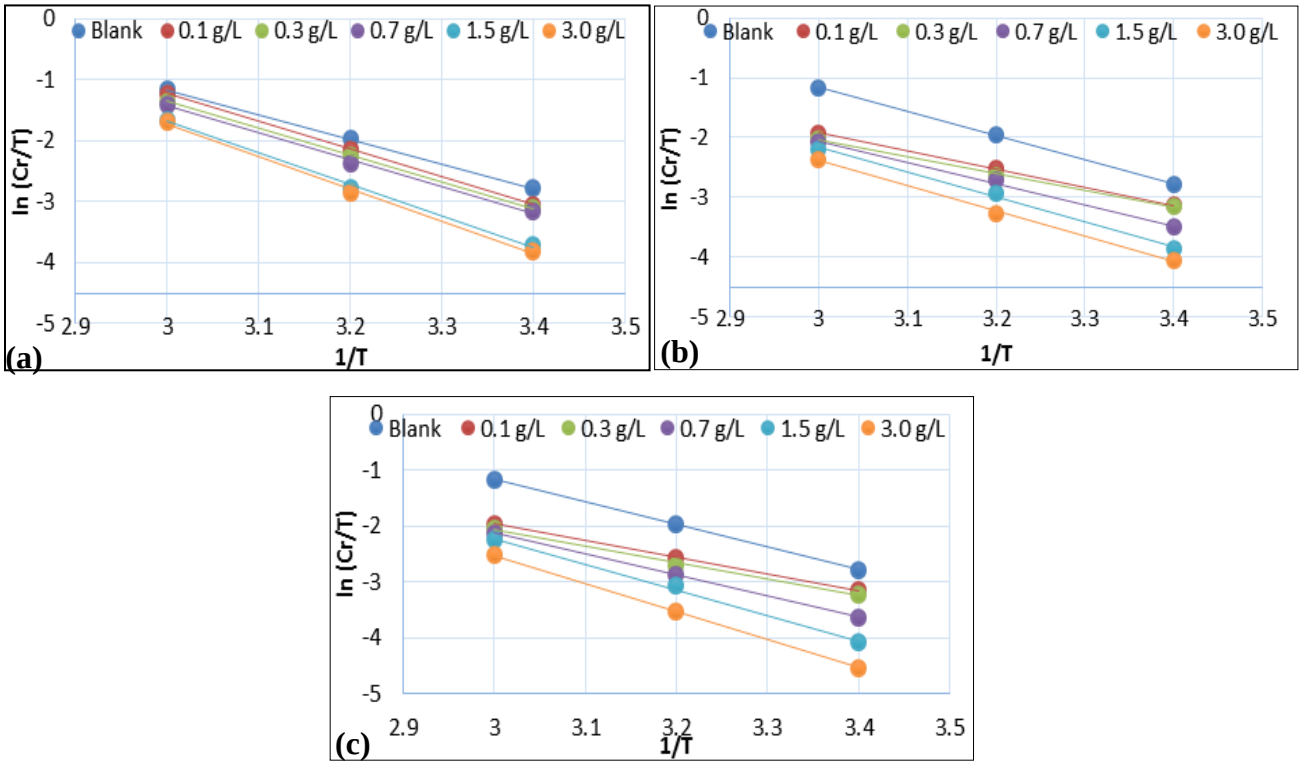


Fig 8: Transition state plots for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

Table 5: Thermodynamic data for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

	Setol				Fetol				Aetol			
Conc. (g/L)	**lnA**	**Ea**	**ΔHads kJ/mol**	**ΔSads kJ/mol**	**lnA**	**Ea**	**ΔHads kJ/mol**	**ΔSads kJ/mol**	**lnA**	**Ea**	**ΔHads kJ/mol**	**ΔSads kJ/mol**
Blank (1 M H2SO4)	2.09	11.91	43.10	-96.77	2.09	11.91	43.10	-96.77	2.09	11.91	43.10	-96.77
0.5 g/L	2.95	13.03	31.92	-104.26	2.52	12.39	26.54	-127.22	2.54	14.45	19.58	-112.36
1.0 g/L	2.95	13.74	22.27	-129.52	2.58	13.72	20.48	-136.91	2.57	14.86	18.43	-123.13
2.0 g/L	3.00	15.11	19.46	-146.29	2.72	13.93	18.37	-154.23	2.74	15.73	12.49	-127.97
3.5 g/L	3.09	15.64	18.39	-181.46	2.85	14.17	18.06	-159.13	2.94	16.11	11.56	-149.82
7.0 g/L	3.11	16.09	10.12	-214.58	2.86	14.19	13.61	-177.52	3.03	16.29	9.33	-173.55

3.5 Evaluation of adsorption isotherm data

The values obtained from thermometric analysis were theoretically fitted into Langmuir adsorption isotherm model (Figure 9) and the correlation coefficient (R^2) values was used to determine the best fit [18, 20-22]. Langmuir isotherm was found to be a good adsorption isotherm model to describe the adsorption of both SETOL, FETOL and AETOL in 0.2 M HCl solutions. Langmuir isotherm is characterized by Eqn. 6 [31- 33]:

$$\frac{C}{\theta} = \frac{1}{K} + C \qquad (6)$$

where C is the inhibitor concentration and K is the equilibrium constant of the adsorption–desorption process. In all cases, linear plots were obtained and the R^2 values are close to unity (Table 6), suggesting that the adsorption of molecules of *Taraxacum officinale* leaves on stainless steel surface obeys Langmuir adsorption isotherm and a monolayer adsorption can be defined [6, 23-30]. From the values of K_{ads}, the standard free energy of adsorption for both extracts at different temperatures were obtained as follows (Eqn. 7):

$$\Delta G^0_{ads} = RT \ln (55.5Kads) \qquad (7)$$

Where

R is the universal constant, T is the absolute temperature and 55.5 is the concentration of water molecules expressed in mg L^{-1} or ppm. The computed values of ΔG^0_{ads} listed in Table 3 are less negative than -40 kJ mol^{-1} and more negative than -20 kJ mol^{-1} which indicate physisorption involving electrostatic interaction between charged. From the values of ΔG^0_{ads} obtained in this present work, it can be established that adsorption mechanism of both inhibitors on stainless steel surface may involve physisorption [13, 22, 29-35].

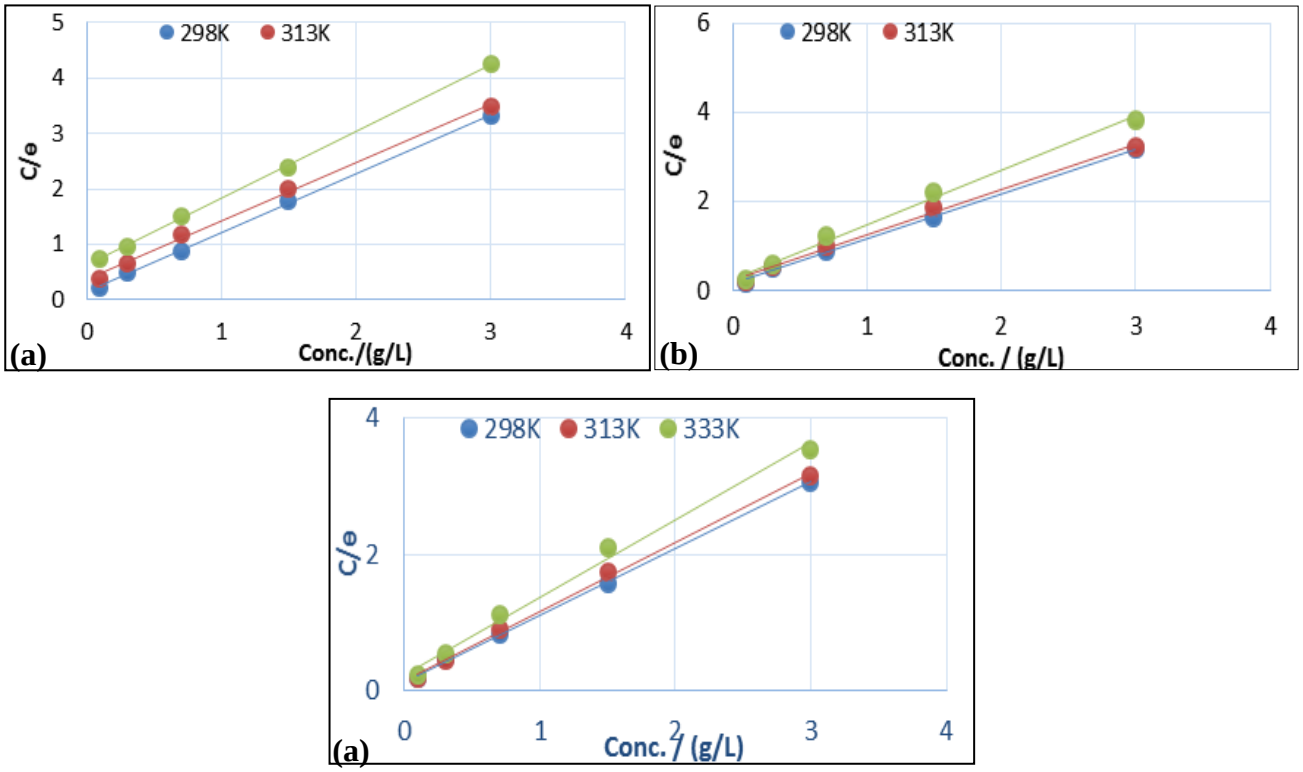


Fig 9: Langmuir isotherm plots for stainless steel corrosion by (a) saponins, (b) flavonoids and (c) alkaloids extracts of *Taraxacum officinale* in 0.2 M HCl medium

Table 6: Adsorption data for the corrosion inhibition of stainless steel by phytochemical constituents of *Taraxacum officinale in* 0.2 M HCl medium

	SETOL				FETOL				AETOL			
Temp. (K)	**k (g/L)**	**R^2**	**Slope**	**ΔG^*_{ads} (kJ/mol)**	**k (g/L)**	**R^2**	**Slope**	**ΔG^*_{ads} (kJ/mol)**	**k (g/L)**	**R^2**	**Slope**	**ΔG^*_{ads} (kJ/mol)**
298	1.60	0.9994	1.2016	-111.15	4.14	0.9933	1.2286	-134.71	4.24	0.9920	1.1318	-135.30
313	2.76	0.9974	1.0585	-130.93	4.53	0.9944	1.0241	-143.83	7.07	0.9980	1.0181	-155.42
333	6.63	0.9992	1.0592	-163.57	6.58	0.9982	1.0073	-163.36	7.66	0.9989	1.9748	-167.56

Conclusion

1. The results from all the experimentations were in agreement as both techniques proved both phytochemical compounds as excellent and reliable corrosion inhibitors of stainless steel in HCl acid solution.
2. The research also suggested that the alkaloid extracts of *Taraxacum officinale* leaves is slightly better inhibitor compared to the saponins and flavonoids extracts which might be due to the strong adsorption of hetero-atoms on the steel surface.
3. The thermodynamic data suggested that the inhibitors are reliable, spontaneous and stable on the stainless steel surface.
4. The adsorption data suggested a physical adsorption mechanism and a monolayer adsorption process, in obedience to the Langmuir adsorption isotherm.
5. Electrochemical results revealed corrosion retardation of both the anodic dissolution of the metal and cathodic hydrogen evolution, hence mixed type inhibitors.

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