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Chemical composition, anticorrosion and antioxidant activity of clove (*Syzygium aromaticum*) oil

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ABSTRACT

The effect of clove (*Syzygium aromaticum*) oil (CO) on mild steel corrosion was investigated in hydrochloric acid (1M HCl) solution by using electrochemical techniques. The results show that the oil acts as mixed-type inhibitor with the highest inhibition at 0,8g/L. The inhibition of corrosion is found to be due to adsorption of this essential oil on metal surface, which is in conformity with Langmuir's adsorption isotherm. Electrochemical impedance spectroscopy results showed that the corrosion and corrosion inhibition of steel occurred mainly by charge transfer. Furthermore, the antioxidant activities of clove oil was evaluated by employing two antioxidant assay such as α,α-diphenyl-β-picryl-hydrazyl free radical (DPPH.) scavenging and ferric ion (Fe^{3+}) reducing antioxidant power assay (FRAP).

Key Words: Antioxidant activity; Corrosion inhibition; Syzygium aromaticum oil; Mild steel.

INTRODUCTION

Corrosion of metals is a common problem with economic implications costing billions of dollars each year. Corrosion inhibition is required by many industries, for example oil and gas exploration and production, petroleum refining and chemical manufacture (Schmitt et al., 1985). The use of inhibitors is one of the most effective ways to prevent corrosion. Inhibitors are commonly used to reduce the corrosive attack of solutions to the contacted metallic materials. The majority of well-known inhibitors are organic compounds containing heteroatoms such as O, N and S with multiple bonds. The efficiency of these organic corrosion inhibitors is related to the presence of polar functional groups with S, O and N atoms in the molecule (Zarrok et al., 2012a; b; Zarrouk et al., 2011; Zarrouk et al., 2012; Zarrok et al., 2013; Ghazoui et al., 2014). Nevertheless, most of these organic compounds are not only expensive but also toxic to both human beings and the environment (El-Etre et al., 2006). Therefore, the investigation of new cost-effective, non-toxic and eco-friendly inhibitors is essential to get over this problem and has been addressing toward the goal of using cheap, effective compounds at low or ‘‘zero’’ environmental impact.

Natural products are nontoxic, biodegradable and readily available. They have been used widely as inhibitors. Many research groups have reported the successful use of naturally plant-derived substances to restrain the metal corrosion (Gunasekaran et al., 2004; Abiola et al., 2009; da Rocha et al., 2010; Torres et al., 2011; Khadraoui et al., 2014; Hamdani et al., 2015a; b; Lotfi et al., 2015).

The encouraging results obtained by naturally oils as corrosion inhibitor of steel in acid solutions permit to test more substance oils. There is no report to our knowledge on the effect of the addition of clove (*Syzygium aromaticum*) Essential Oil on the corrosion of mild steel alloy in hydrochloride solution. In the view of the results obtained by antioxidant investigation, it was found worth investigating the corrosion inhibition behavior of this of clove (*S. aromaticum*) Essential Oil. Hence, the present paper reports the results of our investigation on the inhibitive performance of the clove (*S. aromaticum*) Essential Oil on mild steel in HCl medium using electrochemical techniques. The free radical 2, 2-diphenyl-1-picrylhydrazyl (DPPH) and ferric ion (Fe^{3+}) reducing antioxidant power assay (FRAP) method was used for antioxidant assay of clove (*S. aromaticum*) essential oil.

MATERIALS AND METHODS

Essential oil extraction: A total of 100g clove were subjected to hydro-distillation for 3h with 600ml distilled water using a Clevenger-type apparatus modified: the hydrosol was collected in a separatory funnel (1 liter) so that the heavy oil was decanted to the bottom of the flask. While the water of the hydrosol was recycled into the flask containing the plant material in boiling. The essential oil obtained was collected and dried over anhydrous sodium sulphate and stored in a refrigerator at 4-5°C prior to analysis. Yield based on dried weight of the sample was calculated.

Characterization of *Syzygium aromaticum* Essential Oil

Gas chromatography analysis: The isolated oil was diluted with hexane (dilution ratio 10:100), and was sampled for the gas chromatographic analysis. Trace gas chromatograph (GC) (ULTRA S/N 20062969, Thermo Fischer), gas chromatograph equipped with HP-5MS non polar fused silica capillary column (60m×0.32mm, film thickness 0.25 mm) was used. Operating conditions: oven temperature program from 50°C (2 min) to 280°C at 5°C/min and the final temperature kept for 10 min, 2 “split mode” ratio 1:20, carrier gas Azoth (N), flow rate 1ml/ min, temperature of injector and detector (flame ionization detector) were fixed at 250°C and 280°C, respectively.

Gas chromatography-mass spectrometry (GC-MS: The analysis of the volatile constituents was run on a Thermo Fischer capillary gas chromatograph directly coupled to the mass spectrometer system (model GC ULTRA S/N 20062969, Polaris QS/N 210729), using an HP-5MS non polar fused silica capillary column (60m×0.32 mm, 0.25mm film thickness). The operating condition of GC oven temperature was maintained as: initial temperature 40°C for 2 min, programmed rate 2°C/min up to final temperature 260°C with isotherm for 10 min, injector temperature 250°C. The carrier gas was helium, flow rate 1ml/ min. Samples were run in hexane with a dilution ratio of 10:100. The volume of injected specimen was 1ml of diluted oil, splitless injection technique, ionization energy 70 eV, in the electronic ionization mode, ion source temperature 200°C, scan mass range ofm/z 40-650 and interface line temperature 300°C. Components identification was made by determination of their retention indices (KI) relative to those of a homologous series of n-alkanes (C_8-C_{20}) (Fluka, Buchs/sg, Switzerland) and by matching their recorded mass spectra with those stored in the spectrometer database (NIST MS Library v. 2.0) and the bibliography (Adam, 2001).

Materials: The steel used in this study is mild steel with a chemical composition 0.09 wt. % P, 0.38 wt. % Si, 0.01 wt. % Al, 0.05 wt. % Mn, 0.21 wt. % C, 0.05 wt. % S and the remainder iron (Fe).

Preparation of solutions: The aggressive solutions of 1M HCl were prepared by dilution of analytical grade 37% HCl with distilled water. Inhibitor were dissolved in acid solution at the required concentrations (g/L) (volume of inhibitor/volume of blank), and the solution in the absence of inhibitor was taken as blank for comparison purposes. The test solutions were freshly prepared before each experiment by adding essential oil of clove directly to the corrosive solution. Concentrations of essential oils are 0.2, 0.4, 0.6 and 0.8g/L.

Corrosion tests

Electrochemical measurements: The electrochemical measurements were carried out using Volta lab (Tacussel-Radiometer PGZ 100) potentiostate and controlled by Tacussel corrosion analysis software model (Voltamaster 4) at under static condition. The corrosion cell used had three electrodes. The reference electrode was a saturated calomel electrode (SCE). A platinum electrode was used as auxiliary electrode of surface area of 1.0 cm^2. The working electrode was mild steel of the surface 1.0cm^2. All potentials given in this study were referred to this reference electrode. The working electrode was immersed in test solution for 30min to a establish steady state open circuit potential (E_{ocp}). After measuring the E_{ocp}, the electrochemical measurements were performed. All electrochemical tests have been performed in aerated solutions at 308K. The EIS experiments were conducted in the frequency range with high limit of 100kHz and different low limit 10mHz at open circuit potential, with 10 points per decade, at the rest potential, after 30min of acid immersion, by applying 10mV ac voltage peak-to-peak. Nyquist plots were made from these experiments. The best semicircle can be fit through the data points in the Nyquist plot using a non-linear least square fit so as to give the intersections with the *x*-axis. The impedance data were analysed and fitted with the simulation ZView 2.80, equivalent circuit software.

After ac impedance test, the potentiodynamic polarization measurements of mild steel substrate in inhibited and uninhibited solution were scanned from cathodic to the anodic direction, with a scan rate of 0.5 mV s^{-1}. The potentiodynamic data were analysed using the polarization VoltaMaster 4 software. The linear Tafel segments of anodic and cathodic curves were extrapolated to corrosion potential to obtain corrosion current densities (I_{corr}).

From the polarization curves obtained, the corrosion current (I_{corr}) was calculated by Tafel extrapolation using the equation:

$$I = I_{corr}\left[exp\left(\frac{2.3\Delta E}{\beta_a}\right) - exp\left(\frac{2.3\Delta E}{\beta_c}\right)\right] \qquad (1)$$

The inhibition efficiency was evaluated from the measured I_{corr} values using the following relationship:

$$\eta_{Tafel}(\%) = \frac{I_{corr} - I_{corr(i)}}{I_{corr}} \times 100 \qquad (2)$$

- Where I_{corr} and $I_{corr(i)}$ are the corrosion current densities for steel electrode in the uninhibited and inhibited solutions, respectively.

Antioxidant activity

DPPH scavenging activity: The DPPH method was introduced by Blois (Blois, 1958). The ability of essential oils to scavenge the DPPH radical was measured using the method by (Wu et al., 2003). 0.1ml of various concentrations of extracts or standard was added with 1.5 ml of ethanolic solution containing 0.1mmol of DPPH (2,2-diphenyl-1-picrylhydrazyl). Absorbance measurements were read at 517nm. The absorbance of the mixture was measured at 517 nm with a spectrophotometer (Jasco V-530) after 30 min of incubation time at room temperature in dark.

The percentage inhibition was calculated by the following equation:

$$I(\%) = \left(\frac{A_{Blank} - A_{Sample}}{A_{Blank}} \right) \times 100 \qquad (3)$$

- A_{Blank} : Absorbance of the blank (containing all reagents except for the test compound),
- A_{Sample} : Absorbance of the test compound.
- BHT served as positive control. The IC_{50} values were calculated as the concentration of causing a 50% inhibition of DPPH radical.

Reducing power assay (FRAP): The reducing capacity of the tested oils was determined in accordance with the procedure of Oyaizu (Oyaizu, 1986).100µl of the oils was mixed with 500µl of phosphate buffer (0.2M, pH6.6) and 500µl of potassium ferricyanide $[K_3Fe\ (CN)\ _6]$1%. The obtained solution was incubated at 50°C for 20min.The mixture was acidified with 500µl of Trichloracetic (TCA) 10% which was then centrifuged at 3000 rpm for 10 min. The upper layer of the solution (2,5ml) was mixed with 500µl of distilled water and 100 µl of $FeCl_3$ (0.1%), and the absorbance was measured at 700nm with a spectrophotometer (Jasco v-530). BHT and Ascorbic acid was used as standard. The result was expressed as IC_{50} (mg/ml). The oil concentration corresponding 0.5 of absorbance (EC_{50}) was calculated by polotting absorbance against the corresponding oil concentration. All samples were analyzed in triplicate.

RESULTS AND DISCUSSION

Chemical composition of clove oil: The present work evaluated the chemical composition of CO. The main compounds of *Syzygium aromaticum* EO determined by GC-MS and GC-FID are listed in Table 1.

Table-1: Constituents of *Syzygium aromaticum* essential oil and their relative percentages of total chromatogram area and Kovats index.

Compounds	Kovats index	(%)
Eugenol	1353	87.03
β-Caryophyllene	1428	< 1
Acetate eugenol	1538	11.25
Caryophyllene oxide	1689	< 1

Potentiodynamic polarization measurements: Potentiodynamic polarization measurements were carried out to know the effect of inhibitor on the kinetics of anodic and cathodic reactions, and also to obtain information about the nature of the inhibitor. The polarization curves of mild steel in 1M HCl solution in the absence and presence of different concentrations of CO are shown in Figure 1. Electrochemical polarization parameters such as corrosion potential (E_{corr}), corrosion current density (I_{corr}), cathodic tafel slope (β_c) and inhibition efficiency (η_{Tafel} %) are tabulated in Table 2.

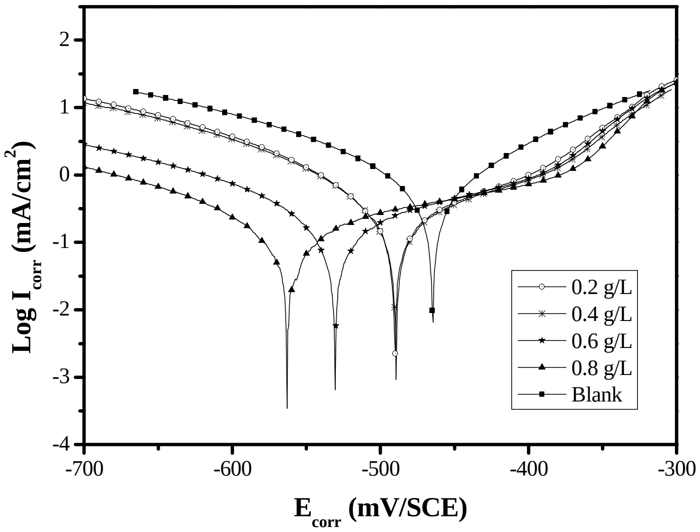

Figure-1: Polarization curves for mild steel in 1 MHCl at different concentrations of CO at 308 K.

It is clear that the addition of essential oil of clove (*Syzygium aromaticum*) to the acid solution decreases the corrosion current density (I_{corr}). This indicates that CO retards the rate of corrosion of mild steel. The inhibition of corrosion increases with increase in CO concentration in acidic medium. Inspection of the Figure 1 and Table 2 shows that CO has an inhibitive effect in the both anodic and cathodic parts of the polarization curves and the addition of CO shifted the E_{corr} value towards the negative direction compared to the uninhibited mild steel.

The corrosion current density (I_{corr}) decreases considerably with increasing CO concentration, while a clear trend was observed in the evolution of E_{corr} values. The cathodic Tafel slope (β_c) values show slight changes with the addition of CO, which suggests that the inhibiting action occurred by simple blocking of the available cathodic sites on the metal surface, which lead to a decrease in the exposed area necessary for hydrogen reduction and lowered the dissolution rate with increasing CO concentration. The result also reveals that the addition of the CO affected significantly the values of E_{corr}, indicating the mixed type nature of the CO on inhibition of corrosion on metal steel with predominance cathodic (Ibrahim et al., 2012, Oguzie 2007). The dependence of protection efficiency η_{Tafel}(%) versus the inhibitor concentration of CO is also presented in Table 2. The obtained inhibition efficiencies indicate that this inhibitor acts as effective inhibitor and η_{Tafel} (%) increases as CO concentration increases, reaching its maximum value at 0.8g/L (90%).

Table-2: Polarization data of mild steel in 1M HCl containing different con. of CO at 308 K.

Conc. (g/L)	$-E_{corr}$ (mV vs SCE)	$-\beta_c$ (mV dec^{-1})	I_{corr} (µA cm^{-2})	η_{Tafel} (%)
Blank	464.0	207	1870	—
0.2	490.7	185	374	80
0.4	489.9	245	318	83
0.6	531.0	165	243	87
0.8	563.0	175	187	90

EIS measurements: The Nyquist plots in the absence and presence of different studied concentrations of the CO are shown in Figure 2. Nyquist plots give one semicircle in the absence and presence of different concentrations of CO suggesting that inhibition of metallic corrosion taking place in the present study is due to retardation of electron charge transfer process. Deviation from the perfect semicircle is generally attributed to the frequency dispersion as well as to the inhomogeneities of the surface and mass transport resistant (Seikh and Sherif, 2015). The diameter of the Nyquist plots increases with increasing concentration suggesting that values of charged transfer resistance (R_{ct}) increase due to formation of protective film. The impedance parameters were derived using equivalent circuit described elsewhere (Verma et al., 2014) and is given in Table 3. The equivalent circuit consists of solution resistance (R_s), charge transfer resistance (R_{ct}) and a constant phase element (CPE) (Figure 3), which consists of R_s solution resistance, R_{ct} charge transfer resistance and CPE constant phase elements for the double layer. A constant phase element (CPE) is used instead of a pure capacitor to compensate the non-ideal capacitive response of the interface and to get a more accurate fit of experimental data set.

Its impedance is given by Eq. (4):

$$Z_{CPE} = \frac{1}{A(i\omega)^n} \qquad (4)$$

- Where A (Ω^{-1} s^n cm^{-2}) is the magnitude of the CPE, w (rad s^{-1}) is the sine wave modulation angular frequency, $i^2 = -1$ is the imaginary number and n is an empirical exponent which measures the deviation from the ideal capacitive behaviour (Lopez et al., 2003, El-Hajjaji et al., 2018). Depending on the values of n, CPE can represent resistance (n = 0), capacitance (n = 1), inductance (n = -1) and Warburg impedance (n = 0.5) (Amin et al., 2010, Musa et al., 2010, Zheng et al., 2014). The values of R_{ct} in the absence and presence of different concentrations of CO were obtained by fitting EIS data in this equivalent circuit.

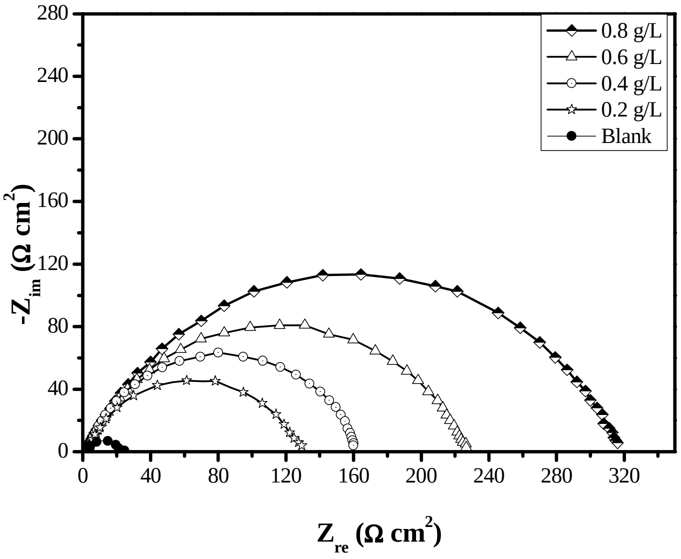

Figure-2: Nyquist plot of mild steel corrosion in 1M HCl in the absence and presence of different concentrations of CO.

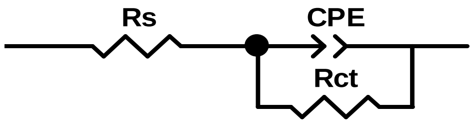

Figure-3: Equivalent circuit model used to fit the EIS data.

From the calculated values of R_{ct}, the value of double layer capacitance (C_{dl}) in the absence and presence of CO was calculated using the following equation (Shih and Mansfeld, 1989):

$$C_{dl} = \sqrt[n]{A\ (R_{ct})^{1-n}} \tag{5}$$

and the relaxation time constant (τ) of charge-transfer process using the Eq. (6) (Popova et al., 2007):

$$\tau = C_{dl} R_{ct} \tag{6}$$

The inhibition efficiency in the case of ac impedance study, η_Z(%), was evaluated by R_{ct} values using Eq. (7), where R_{ct} and $R_{ct(i)}$ were the charge transfer resistance of mild steel electrode in the uninhibited and inhibited solutions, respectively (Lebrini et al., 2008).

$$\eta_Z\,(\%) = \frac{R_{ct(i)} - R_{ct}}{R_{ct(i)}} \times 100 \tag{7}$$

Table-3: EIS parameters obtained for mild steel in 1M HCl in the absence and presence of different concentrations of CO.

Medium		**R_s (Ω cm^2)**	**10^6A $\Omega^{-1}s^n\,cm^{-2}$**	**n**	**R_{ct} (Ω cm^2)**	**C_{dl} (µF cm^{-2})**	**τ (ms)**	**η_Z (%)**
Blank		2.02	508.91	0.800	20.35	158.89	3.23	—
CO	0.2g/L	2.01	284.26	0.788	123.6	115.47	14.27	83.5
	0.4g/L	2.17	235.19	0.789	162.0	98.16	15.90	87.4
	0.6g/L	2.09	196.91	0.798	220.6	73.99	16.32	90.8
	0.8g/L	2.06	133.4	0.796	307.3	58.83	18.09	93.4

R_{ct} increases with the concentration of CO and reaches a maximum value of 307.3Ω cm^2 at 0.8g/L. This increase demonstrates the improved protection effect of this compound and a slow corroding system, due to the gradual replacement of water molecules by CO molecules on the surface and consequently to a decrease in the number of active sites necessary for the corrosion reaction (Popova et al.,1996).

The value of the proportional factor A of CPE varies in a regular manner with inhibitor concentration. However, the values of the phase shift (n) did not vary significantly, confirming therefore that the charge transfer controlled dissolution mechanism of mild steel in 1M HCl without and with inhibitor. After addition of CO in the corrosive solution, n values (ranges from 0.788 to 0.796) decrease, when compared to that obtained in pure 1M HCl (0.800). This shows an increase of the surface inhomogeneity as a result of the inhibitor's adsorption (Growcock et al., 1989). It is worth mentioning that the value of the relaxation time constant (τ) slowly increases with CO concentration as well and the time of adsorption process becomes therefore much higher which means a slow adsorption process (Outirite et al., 2010, Morales et al., 2008). However, the addition of CO to the corrosive solution decreases the double layer capacitance (C_{dl}) (Table 3).

The decrease in C_{dl} can result from the decrease of the local dielectric constant or increase of thickness of electrical double layer, which suggest the substitution of H_2O molecules (with higher dielectric constant) with inhibitor molecules (with lower dielectric constant) leading to the formation of a thin protective film on the electrode surface (Ozcan et al., 2008). However, the more the adsorption of inhibitor molecules on the metal surface, the more the thickness of the barrier layer is increased according to the expression of the Helmholtz model (Ahamad et al., 2010).

$$C_{dl} = \frac{\varepsilon_0 \varepsilon}{d} S \quad \textbf{(8)}$$

- Where ε_0 is the permittivity of free space, ε is the local dielectric constant of medium, and S is the surface area of the electrode.

Equation 8 suggests that C_{dl} is inversely proportional to the thickness of protective layer d.

Adsorption isotherm: The values of surface coverage to different concentrations of inhibitors, obtained from EIS measurements at 308 K, have been used to explain the best isotherm to determine the adsorption process. Adsorption isotherms are very important in determining the mechanism of organo-electrochemical reactions (Ali et al., 2003). The most frequently used isotherms are Langmiur, Temkin, Frumkin, Parsons, Hill de Boer, Flory-Huggins and Dahar-Flory-Huggins and Bockris-Swinkel. However, the best fit is obtained from Langmuir isotherm (Figure 4). All these isotherms are of the general form:

$$\int(\theta, x)\exp(2a\theta) = KC_{inh} \quad (9)$$

- Where $\int(\theta,x)$ is the configurational factor which depends upon the physical model and the assumptions underlying the derivation of the isotherm. "θ" is the surface coverage degree, "*C*" is the inhibitor concentration in the bulk of solution "a" is the lateral interaction term describing the molecular interactions in the adsorption layer and the heterogeneity of the surface. "*K*" is the adsorption-desorption equilibrium constant.

The surface coverage θ for different concentrations of CO in 1M HCl at 308 K has been evaluated from EIS. The data were tested graphically, see Figure 5, by fitting to Langmuir isotherm which given by equation 10.

$$\frac{C_{inh}}{\theta} = \frac{1}{K_{ads}} + C_{inh} \quad (10)$$

- Where C_{inh} is the equilibrium inhibitor concentration, K_{ads} adsorptive equilibrium constant, θ representing the degree of adsorption (η_Z%/100).

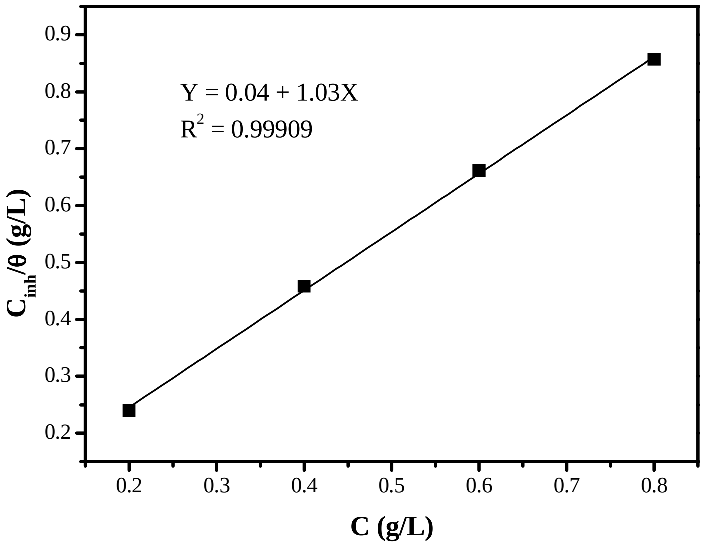

Figure-4: Langmuir adsorption isotherm for mild steel in 1M HCl solution of CO at different concentrations by EIS methods.

From the intercepts of the straight lines C/θ - axis, the K value was calculated, K = 25 L/g. K is related to the standard Gibbs free energy of adsorption, ΔG°_{ads} , according to:

$$K = \frac{1}{C_{H_2O}} \exp\left(\frac{-\Delta G^{\circ}_{ads}}{RT}\right) \qquad (11)$$

- Where R is the universal gas constant, T the thermodynamic temperature and the concentration of water in the solution is 1000g/L.

Generally, for values of ΔG°_{ads} around -20kJ mol^{-1} or less negative, the type of adsorption is regarded as physisorption, those around -40 kJ mol^{-1} or more negative are associated with chemisorption (Bahrami et al., 2010, Behpour et al., 2010). However, it is difficult to distinguish between chemisorption and physisorption only based on these criteria, especially when charged species are adsorbed. The possibility of Coulomb interactions between adsorbed cations and specifically adsorbed anions can increase the Gibbs energy even if no chemical bond appears (Singh et al., 2011). However, the calculation of the ΔG°_{ads} value of CO is not possible because the molecular mass of the extract components is not known. This limitation is noted by some authors in the case of the plant extracts used as corrosion inhibitors for steel in acidic media (Lebrini et al., 2011, Faustin et al., 2015)

Antioxidant Activity: The antioxidant effect of plant samples can be evaluated by several in vitro tests. Since the assay results of the antioxidant effect depend on the method used, a combined assay of several methods is required (Müller et al., 2011). In this study, the antioxidant activity of CO was determined using DPPH, and FRAP assays and was compared with synthetic antioxidant butyl hydroxyl toluene (BHT) used as reference.

DPPH· free radical scavenging activity: DPPH assay is an excellent method to evaluate the radical scavenging activity of potential antioxidative compounds. The DPPH assay has been widely used for the determination of primary antioxidant capacity. DPPH radical could be decreased by reactions with antioxidant compositions that can donate hydrogen (Kumaran et al., 2007). The free radical scavenging ability of antioxidants can be determined by using stable free radicals like DPPH. The purple colour of DPPH radical disappears by abstracting a hydrogen atom from the antioxidant. The Figure 5 shows the analysis of DPPH radical scavenging activity of clove oil and BHA (as a reference compound).

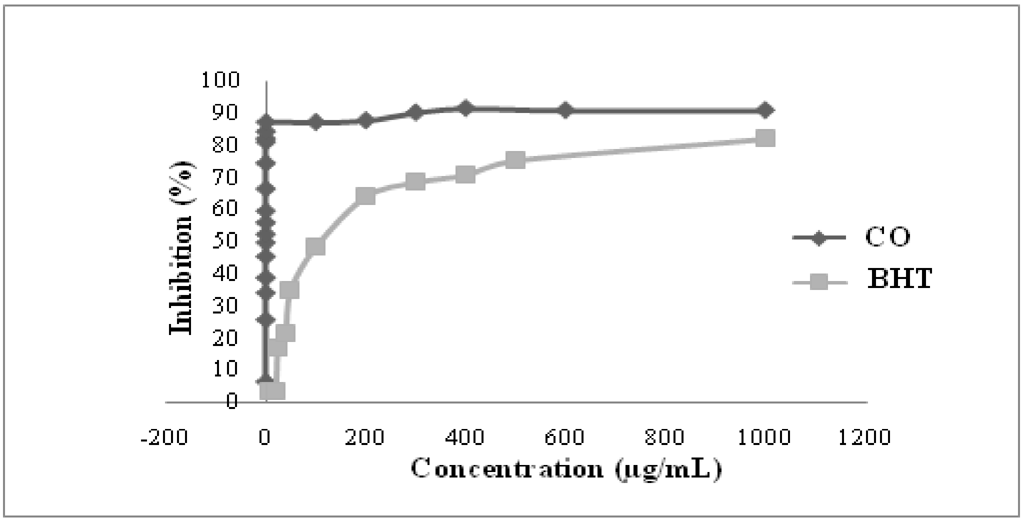

Figure-5: DPPH· Free radical scavenging activity of BHT and *Syzygium aromaticum* essential oil.

Table 4 shows the results of the antioxidant activity measured by the two assays. The IC_{50} value obtained by DPPH free radical-scavenging assay was 0.063µg/ml for Clove oil. This value is significantly ($P < 0.05$) 2000 times lower than that of the standard antioxidant BHT where $IC_{50}$was achieved at 100µg/ml. On DPPH assay, IC_{50} values were obtained for clove oil and BHA, so that a lower value of IC_{50} indicated a higher antioxidant activity and reciprocally.

Table-4: IC_{50} and EC_{50}values of respectively DPPH Reaction and FRAP reaction.

Samples	**IC_{50}(µg/ml) Values of DPPH reaction**	**EC_{50}(µg/ml) values of FRAP reaction**
Clove Essential Oil	0.063 ± 0.0004	0.058 ± 0.0012
BHT	100 ± 4.2	120 ± 5.71

Ferric ions (Fe^{3+}) reducing antioxidant power assay (FRAP): The FRAP method is commonly applied to evaluate the antioxidant activity of plant materials, and it measures the capacity of the sample to reduce ferric ion Fe^{3+} to the ferrous Fe^{2+} form (Contreras-calderon et al., 2011). The reducing power of clove oil increased steadily with increasing concentration of samples (Figure 6). At different concentrations (0.02-0.16µg/ml), clove oil demonstrated powerful reducing ability. As displayed in Table 4, the FRAP value of the Clove oil was significantly ($P< 0.05$) 2000 times lower (EC_{50} of 0.058µg/ml) than of BHT where EC_{50} was 120µg/ml.

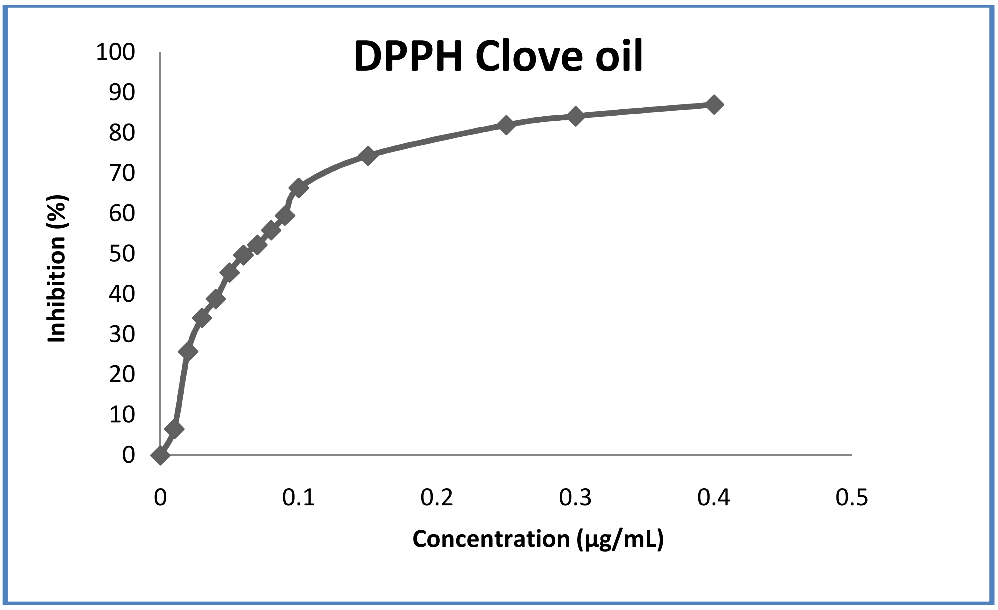

Figure-6: Reducing power activity of *Syzygium aromaticum* essential oil.

Our results were in good agreement with recent previously reported results showed that the Clove oil show greater antioxidant activity compared to those of standard antioxidant (Gülçin et al., 2012). On the other hand, the higher antioxidant activity of Clove oil is probably likely to their higher Eugenol and Acetate eugenol Acetate contents (Table 1).

CONCLUSION

Syzygium aromaticum Essential Oil has significant antioxidant activity, CO exhibit corrosion inhibition properties for mild steel in 1M HCl. The inhibiting effect increases with the increase of the oil concentration to reach a maximum at 0.8g/L. Potentiondynamic polarization measurements demonstrate that inhibitor acts as a mixed-type inhibition with predominance cathodic. The adsorption of CO on the mild steel surface follows the Langmuir adsorption isotherm. Data obtained from ac impedance technique show a frequency distribution and therefore a modelling element with frequency dispersion behaviour, a constant phase element (CPE) has been used.

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