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Anticorrosion properties of *Thymus munbyanus* Boiss & Reut essential oil for mild steel in 1M HCl

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Abstract

The *Thymus munbyanus* Boiss & Reut essential oil analysis (TM oil) by GC and led to the identification of 29 components accounting for (97.8%) of the total oils were identified. The main compounds of TM oil were carvacrol (31.7%), □-terpinene (21.9%), p-cymene (14.7%), thymol (7.6%), linalool (4.3%), borneol (3.9%) and α-terpinene (2.1%). The TM oil effect against the corrosion of mild steel in 1M HCl solution has been checked by weight loss measurement as well as potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) assays. The gravimetric results indicate that TM oil exhibited good inhibition efficiency in 1M HCl medium. The polarization measurements showed that TM oil is a mixed type with a significant reduction of cathodic and anodic current densities. Electrochemical impedance spectroscopy measurements revealed that the charge transfer resistance increased by increasing the essential oil concentration, which suggests Langmuir isotherm model as a most suitable adsorption mechanism.

Keywords: Essential oil, *Thymus munbyanus*, GC/MS, Anticorrosion activity.

1. Introduction

Recently many researches have been focused on the possibility of the use of essential oils as corrosion inhibition of metal in different mediums. This occupation of scientists is justified by the richness and diversity of the composition of these natural crudes. They are therefore potential candidates to replace synthetic products used in this field and how are known for their harmful impact on the environment and human health. However, the characterization of essential oils is a vital step before engaging in the study of their possible use as an inhibitor of corrosion [1]. Continuing our research in this area, we are interested in this paper to the study to the possibility to use of *Thymus munbyanus* Boiss & Reut essential oil as a green inhibitor of corrosion of steel in acid media, in relation to his constituents. In Morocco, this plant is represented by many species of which certain are endemic. However, the thyme has been used in Moroccan folk medicine, in the treatment of diarrhea, fever, cough, infected areas and wounds. It was also used as a tonic and stimulant [2,3]. Generally, the thyme is known for its anti-inflammatory, antimicrobial and antiviral properties [4–6].

2. Materials and methods

2.1. Plant material and preparation of essential oils

The *Thymus munbyanus* Boiss & Reut aerial parts, were collected during the full flowering period of the plants (May 2016) in the mountains of Lhajeb (Morocco). Voucher specimen was deposited in the Sciences Faculty of Marrakech (Morocco) herbarium. The vegetal materials were dried at ambient temperature. The sampled plants were treated separately for extracting essential oils. 100g of dried vegetal materials were water-distillated (3h) using a Clevenger-type apparatus [7]. The extracted essential oils were dried over anhydrous sodium sulphate, filtered and stored at 4°C until analyzed and used.

2.3. GC and GC–MS analysis

The *Thymus munbyanus* Boiss & Reut essential oils were analyzed using a Perkin-Elmer Turbo mass detector, according to a reported method of Paolini et al. [8].

3. Anticorrosion activity

3.1. Preparation of materials

The samples used in this investigation were cylindrical discs cut from a mild steel rod with the composition; 0.1 wt.% (P), 0.38 wt.% (Si), 0.02 wt.% (Al), 0.05 wt.% (Mn), 0.25 wt.% (C), 0.07 wt.% (S) and the remainder iron (Fe) used for weight loss measurements. The disc was fitted by silicon on a plastic tube as a holder, leaving the surface area exposed to the corrosive electrolyte. The surface preparation of the mild steel was carried out with emery papers by increasing grades (800, 1200 and 4000 grit size), rinsed with distilled water, degreased in acetone in an ultrasonic bath immersion for 5min, washed again with bidistilled water and then dried at room temperature before use. The aggressive solution of 1M HCl was prepared by dilution of analytical grade 37% HCl with double distilled water. The concentration range of the essential oil of *Thymus munbyanus* was 0.5–3g/L. This concentration range was chosen upon the maximum solubility of TM oil.

3.2. Weight loss measurements

The weight loss measurements were conducted under total immersion in stagnant aerated condition using 250 mL capacity beakers containing 100 mL in 1M HCl with and without the presence of different concentrations of essential oil of *Thymus munbyanus* ranging from 0.5 to 3g/L at temperature (298K). After 6h of immersion, the specimens of

steel were carefully washed in double-distilled water, dried and then weighed. Triplicate experiments were performed in each case and the mean value of the weight loss is reported using an analytical balance (precision ± 0.0001 mg). Weight loss allowed us to calculate the mean corrosion rate as expressed in $mg/cm^2.h$. The corrosion rate (W) and inhibition efficiency (E%) were calculated from the following equations (1) and (2) respectively:

$$W = \frac{\Delta m}{S \times t} \quad (1)$$

$$E\% = \left(1 - \frac{W_{inh}}{W_0}\right) \times 100 \quad (2)$$

Δm (mg) represents the weight of the sample before and after immersion in the tested solution, W_0 and $W_{(inh)}$ are the values of corrosion weight losses (mg/cm^2h) of mild steel in uninhibited and inhibited solutions, respectively, S is the area of the sample (cm^2) and t is the exposure time (h). The coverage surface was calculated using:

$$\theta = \left(1 - \frac{W_{inh}}{W_0}\right) \quad (3)$$

$W_{(inh)}$ and W_0 are the values of rate corrosion ($mg/cm^2.h$) of mild steel in the presence and absence of TM oil, respectively.

3.3. Electrochemical studies

The electrochemical measurements were performed in a single compartment electrochemical cell designed for mounting varieties of flat samples for electrochemical test with three electrodes system. The working electrode (WE) was the disc-shaped has a radius of 1.4cm and is embedded in polytetrafluoroethylene. A saturated calomel electrode and a disc platinum electrode were used respectively as reference and auxiliary electrodes, respectively. The temperature was thermostatically controlled at 298K.

3.4. Potentiodynamic polarization curves

The polarization curves studies were carried out using EG&G Instruments potentiostat-galvanosta (Model 273A) at 298K without and with addition of various concentrations of TM oil (0.5-3g/L) in 1M HCl medium at a scan rate of 0.5mV/sec. Before recording the cathodic polarisation curves, the mild steel electrode is polarized at -800 mV for 10 min. For anodic curves, the potential of the electrode is swept from its corrosion potential after 30 min at free corrosion potential, to more positive values. The test solution was deaerated with pure nitrogen. Gas bubbling is maintained through the experiments. The open circuit potential (OCP) was allowed to attain a stable state which was achieved after 1800s before the electrochemical measurements were carried out both in the absence and presence of the inhibitor (TM). In the case of polarization method the relation determines the inhibition efficiency (EI %):

$$EI\% = \left(\frac{I_0 - I_{inh}}{I_0}\right) \times 100 \ (4)$$

I_0 and $I_{(inh)}$ represents the corrosion current density values in the absence and presence of TM oil, respectively, obtained by extrapolation of cathodic and anodic Tafel lines to the corrosion potential.

3.5. Electrochemical impedance spectroscopy (EIS)

The electrochemical measurements (recording of open circuit potential (OCP) with time, The electrochemical impedance spectroscopy (EIS), etc ...) were performed using a potentiostat EG&G model 273A controlled by the software CorrWarre, the circular surface of mild steel exposing (2.8cm diameter) to the solution were used as working electrode. After the determination of steady-state current at a given potential, sine wave voltage (10mV) peak to peak, at frequencies between 10^{-2} and 10000Hz. were superimposed on the rest potential. Computer programs automatically

controlled the measurements performed at rest potentials after 30 min of exposure. The values of R_t and C_{dl} were obtained from Nyquist plots. The charge-transfer resistance (R_t) values are calculated from the difference in impedance at lower and higher frequencies, as suggested by Tsuru et al. [9]. The inhibition efficiency got from the charge-transfer resistance is calculated by the following equation (5):

$$ER_t = \left(\frac{R'_t - R_t}{R'_t}\right) \times 100 \quad (5)$$

R_t and R'_t represents the charge-transfer resistance values without and with inhibitor respectively. The double layer capacitance (C_{dl}) and the frequency at which the imaginary component of the impedance is maximal ($-Z_{max}$) are found determined by equation (6):

$$C_{dl} = \frac{1}{\omega . R_t} \quad \text{where } \omega = 2\pi .\text{fmax} \ (6)$$

The impedance diagrams are obtained for frequency range $10000\text{-}10^{-2}$ Hz at the open circuit potential for mild steel in 1M HCl in the presence and absence of inhibitor.

4. Surface characterization: Optical microscope (Leica Microtoposcope & PC-Alicona stereomicroscope Olympus)

The samples were immersed in 1M HCl solution in absence and presence of optimum concentration of the TM oil for 6h immersion time. Then, they were removed, washed with double distilled water, dried and finally analyzed by Optical microscope method.

5. Results and Discussion

5.1. Chemical composition of essential oil

The average yield of *Thymus munbyanus* Boiss & Reut essential oil was calculated based on the dry plant material (1.7±0.10%). The qualitative and quantitative analytical results are shown in Table 1. Oxygenated monoterpenes (48.8%) followed by hydrocarbon monoterpenes (46.5%) are the main groups of constituents in *Thymus munbyanus* essential oil. The chemical composition of TM oil allowed us the identification of 29 compounds representing (97.8%) of the total oil. The carvacrol is the main component (31.8%) in the essential oil followed by □-terpinene (21.9%), p-cymene (14.7%), thymol (7.6%), besides other components with relatively low concentrations; especially linalool (4.3%), borneol (3.9%) and α-terpinene (2.1%) were detected. The analysis of the same species produced from plants harvested in Algeria, shows that carvacrol (35.2%), thymol (18.5%), α-terpineol (7.6%), γ-terpinene (7.0%) and p-cymene (5.1%) are major compounds [10]. These variations encountered in the chemical composition of essential oils of the aerial parts of *Thymus munbyanus* may be due to the part used of the plant [11,12], the vegetative stage of the plant [13,14] or even to genetic factors [15].

Table 1. Chemical composition of *Thymus munbyanus* Boiss & Reut essential oils aerial parts.

Notes: [a]Order of elution are given on apolar column (Rtx-1); [b]Ir j = retention indices on the Joulain; [c]Ira = retention indices on the apolar column (Rtx-1); [d]Irp = retention indices on the polar column (Rtx-Wax); [e]Relative percentages of components (%) are calculated on GC peak areas on the apolar column (Rtx-1) except for components with identical RI a (concentration are given on the polar column). - : not detected.

N[a]	Components	[b]Ir j	[c]Ir a	[d]Ir p	TM[e]
1	α -Thujene	932	923	1026	1.2
2	α-Pinene	936	931	1026	1
3	Camphene	950	944	1072	1.7
4	Oct-1-en-3-ol	963	961	1448	0.4
5	Octan-3-one	964	966	1254	0.1
6	β-Pinene	978	971	1114	0.2
7	Octan-3-ol	981	981	1391	0.1
8	Myrcene	987	981	1163	1.9
9	α-Phellandrene	1002	1001	1168	0.2
10	α-Terpinene	1013	1011	1184	2.1
11	p-Cymene	1015	1013	1275	14.7
12	Limonene	1025	1020	1204	0.4
13	1,8 Cineole	1024	1020	1210	0.2
14	β-Phellandrene	1023	1020	1216	0.2
15	γ-Terpinene	1051	1049	1245	21.9
16	E- Sabinene hydrate	1053	1055	1462	0.6
17	Nonen-3-ol	1058	1065	1522	-
18	Z Linalol oxide THF	1072	1074	1441	0.1
19	p-Cymenene	1075	1076	1436	-
20	Terpinolene	1082	1082	1286	-
21	Linalol	1086	1086	1547	4.3
22	Camphor	1123	1121	1506	0.1
23	Borneol	1150	1152	1700	3.9
24	Terpinen-4-ol	1164	1164	1600	0.6
25	α-Terpineol	1176	1174	1694	0.1
26	Carvacrol methyl ether	1226	1225	1603	-
27	Bornyl acetate	1233	1269	1565	-
28	Linalyl acetate	1239	1242	1557	-
29	Thymol	1267	1278	2180	7.6
30	Carvacrol	1278	1284	2207	31.7
31	trans Caryophyllene	1421	1416	1600	1.4
32	Aromadendrene	1443	1440	1609	-
33	Ledene	1491	1494	1700	0.4
34	E-Nerolidol	1553	1552	2041	0.1
35	Spathulenol	1572	1565	2120	0.2
36	Caryophyllene oxide	1578	1570	1980	0.3
Oxygenated monoterpenes					**48.8**
Hydrocarbon monoterpenes					**46.5**
Oxygenated sesquiterpenes					**0.7**
Hydrocarbon sesquiterpenes					**1.8**
EOs yield (%)					**1.7**
Total identified (%)					**97.8**

5.Anticorrosion activity

4.1.1. Weight loss measurement

The effect of *Thymus munbyanus* Boiss & Reut (0.5–3g/L) on the corrosion of mild steel in 1M HCl medium was studied by weight loss measurements after 6 h of immersion period. The inhibition efficiency values Ew (%) and rate corrosion (W) are gathered in Table 2. From the obtained results, it is very clear that the TM oil inhibits the corrosion of mild steel in 1M HCl, at all concentrations, and the corrosion rate (W) decreases continuously with increasing additive concentration. Indeed, Fig.1 shown that the corrosion rate values of mild steel decrease when the inhibitor concentration increases while Ew(%) values of TM oil increase with the increase of the concentration reaching a maximum value (80.66%) at 3g/L. This behavior can be attributed to the increase of the surface covered θ, and that due to the adsorption of phytochemical components of the essential oil onto the mild steel surface resulting in the blocking of the reaction sites, and protection of the mild steel surface from the attack of the corrosion active ions in the acid medium

Table 2. Corrosion Parameters of mild steel in 1M HCl in absence and presence of different concentrations of *Thymus munbyanus* obtained from weight loss measurements at 298K.

Concentration ($g.L^{-1}$)	W ($mg/cm^2.h$)	Ew (%)	θ
0	13.45	-	-
0.5	7.45	44.60	0.446
1	6.40	52.41	0.524
2	4.88	63.72	0.637
3	2.60	**80.66**	**0.806**

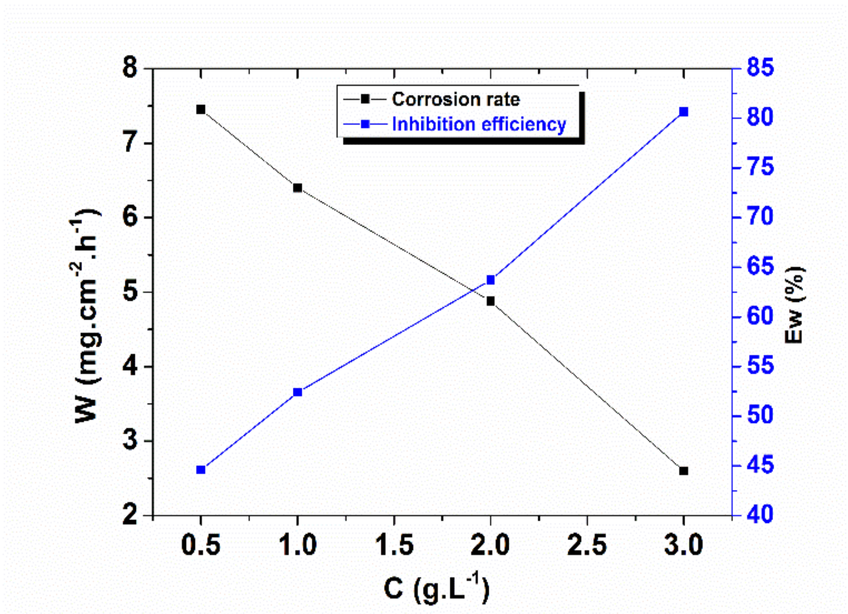

Fig. 1. Variation of corrosion rate (W) and inhibition efficiency (E_w) of corrosion of mild steel in 1M HCl in the presence of TM oil.

4.1.2. Adsorption isotherm and thermodynamic parameters

The adsorption process of inhibitor depends on its electronic characteristics, the metal surface nature, temperature and the varying degrees of surface-site activity. In fact, the solvent H_2O molecules could also be adsorbed at the

metal/solution interface. In the aqueous solution, the adsorption of inhibitor molecules can be considered as a quasi-substitution process between the inhibitor in the aqueous phase Inh(sol) and water molecules at the electrode surface H_2O (ads) [16–18].

$$Org_{(sol)} + xH_2O_{ads} \leftrightarrow xH_2O_{(sol)} + Org_{ads} \quad (7)$$

x represent the size ratio, that is, the number of water molecules replaced by one organic inhibitor.

This equation shows that the interaction force between metal and inhibitor must be greater than the interaction force of metal and water molecule. The corrosion adsorption processes can be understood using adsorption isotherm.

The Langmuir adsorption isotherm is attributing to physisorption or chemisorption phenomenon while Temkin adsorption isotherm gives an explanation about the heterogeneity formed on the metal surface. Chemisorption is attributed to Temkin isotherm [19,20]. However, Langmuir, Frumkin and Temkin adsorption isotherms were applied in order to explain the adsorption process of TM oil on the mild steel surface:

$$\text{Lamgmuir}: \; {C_{inh}}/{\theta} = {1}/{k} + C_{inh} \quad (8)$$

$$\text{Temkin}: \; Ln\left({C_{inh}}/{\theta}\right) = Ln_K - g_\theta \quad (9)$$

$$\text{Frumkin}: Ln\left[C_{inh} * \left(\frac{\theta}{1-\theta}\right)\right] = Ln_K + g_\theta \quad (10)$$

θ represent the coverage surface, K represent the adsorption–desorption equilibrium constant, C_{inh} is the concentration of inhibitor and g is the adsorbate parameter. The regression parameters between C/θ and C are gathered in Table 3, and the straight lines of C/θ versus C in 1M HCl are shown in Fig.2. It is clear that all linear correlation coefficients (R^2) are almost equal to 1, and the slope values are also close to 1, which indicates that the adsorption of TM oil on the surface obeys Langmuir adsorption isotherm. This result showed that the adsorbed molecules occupy only one site and there are no interactions with other adsorbed species [21,22].

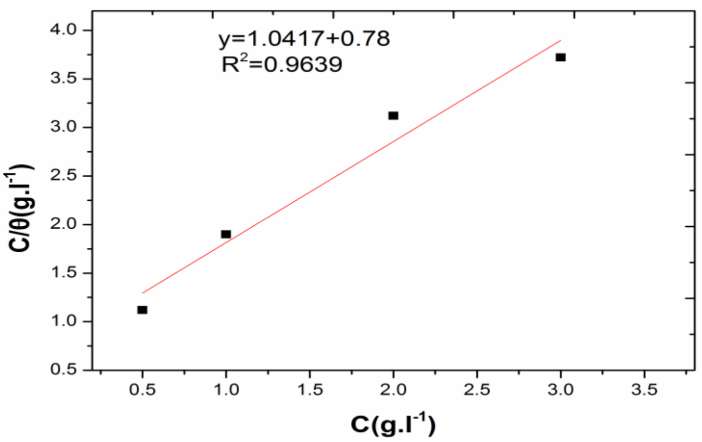

Fig.2. Langmuir isotherm of *Thymus munbyanus* essential oil on the mild steel surface in 1M HCl at 298K.

The thermodynamic parameters are important to better understand the adsorption process of the inhibitor on the steel/solution interface. The equilibrium adsorption constant K is bound to the standard Gibb free adsorption energy (ΔG ° ads) with the following equation:

$$K = \left(\frac{1}{55.5}\right).\exp\left(\frac{\Delta G^0 ads}{RT}\right) \quad (11)$$

R represents the gas constant, T represents the thermodynamic temperature, and the value of 55.5 is the concentration of water in the solution in mol/L (10^3 g/L). The negative values of ΔG°ads (Table. 3) give a tip that the adsorption of molecules inhibition onto steel surface is a spontaneous phenomenon. Also, it is well known that values of ΔG°ads around −20 KJ/mol or lower are associated with the physiosorption where the electrostatic interaction assemble between the charged molecule and the charged metal, while those around −40 KJ/mol or higher are associated with the chemiosorption phenomenon where the sharing or transfer of organic molecules charge with the metal surface occurs [23]. In our present study, the value of ΔG°ads computed and shown in Table.3 supports the physisorption of TM oil on mild steel.

Table 3. Thermodynamic parameters adsorption of *Thymus munbyanus* oil on mild steel in 1M HCl at 298K from Langmuir adsorption isotherm.

4.1.3.

Temperature (K)	R^2	K (L/g)	ΔG° (KJ.mol/L)
298	0.976	1.28	-18.33

Potentiodynamic polarization curves

The anodic and cathodic polarization plots for mild steel in 1M HCl medium in the absence and presence of different concentrations of *T. munbyanus* essential oil at 298K are shown in Fig.3. The kinetic parameters including corrosion current density (I_{corr}), corrosion potential (E_{corr}), cathodic slopes (βc) and inhibition efficiency (IE%) are shown in Table 4.

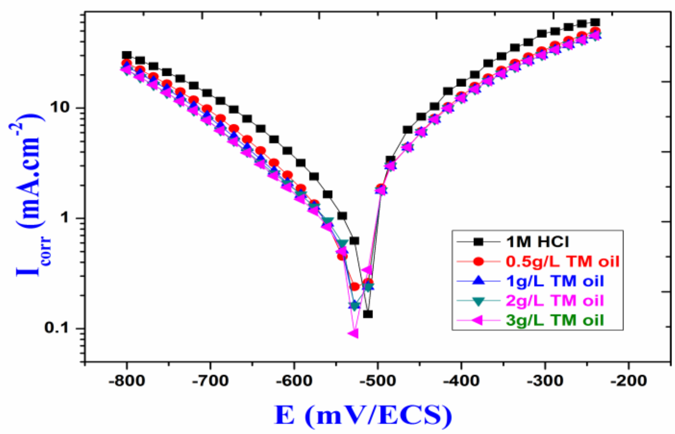

Fig. 3. The anodic and cathodic polarization curves of mild steel in 1M HCl in the presence and absence of different concentrations of *T. munbyanus* essential oil.

The analysis of polarization curves shows that the additive essential oil to the corrosive solution has an inhibitive effect in the anodic and cathodic parts of the polarization curves. This indicates a modification of the mechanism of cathodic hydrogen evolution as well as the anodic dissolution of mild steel, which give a tip that the inhibitor inhibits the corrosion process of steel, and its ability as the corrosion inhibitor is enhanced as its concentration is increased. However, the cathodic Tafel slopes values βc, in the presence of inhibitor, significantly change with the concentration of inhibitor, which indicates the influence on the cathodic reactions and modifies the hydrogen evolution reaction mechanism. From the obtained results (Table 4), the corrosion current densities (I_{corr}) decreases relatively with increasing of inhibitor concentration. Also, the inhibition efficiency (IE%), increases with the inhibitor concentration

to reach its maximum value, 80.32% at 3g/L. The presence of inhibitor caused a slight shift of corrosion potential compared to that in the absence of inhibitor. In our study, the maximum displacement in E_{corr} value was 50 mV for *T. munbyanus* essential oil which indicates that the inhibitors act as mixed type inhibitor [24].

Table 4. Electrochemical parameters of steel at different concentrations of *Thymus munbyanus* Boiss & Reut essential oil in 1M HCl.

Concentration (g/L)	E_{corr} (mV/SCE)	I_{corr} (mA/cm²)	$-\beta_c$ (mV)	E_I%
1M HCl	-470	465	107.56	--
0.5	-460	285.20	175.75	38.66
1	-453	175.60	150.45	62.22
2	-442	81.25	132.11	71.60
3	-420	40.45	91.50	**80.32**

4.1.4. Electrochemical impedance spectroscopy (EIS)

The EIS was used to obtain information about the mechanism and kinetics of the steel corrosion inhibition using *T. munbyanus* essential oil at 298K after exposure period (30 min). The obtained Nyquist plots of mild steel in the absence and presence of *T. munbyanus* essential oil at different concentrations is shown in Fig.4. These diagrams have similar shape throughout all tested conditions, indicating that there is almost no change in the corrosion mechanism which occurs due to the additive inhibitor. The impedance spectra exhibit one single capacitive loop, which indicates that the corrosion of mild steel is mainly controlled by the charge transfer process. Also, the diameter of the capacitive loop in the presence of inhibitor is larger than that in blank solution, and enlarges with the inhibitor concentration [25-27]. The electrochemical parameters of mild steel, such as, charge transfer resistance (R_t), double layer capacitance (C_{dl}) and maximal frequency (f_{max}) derived from Nyquist plots and inhibition efficiency E_{Rt} (%) are calculated and gathered in Table 5.

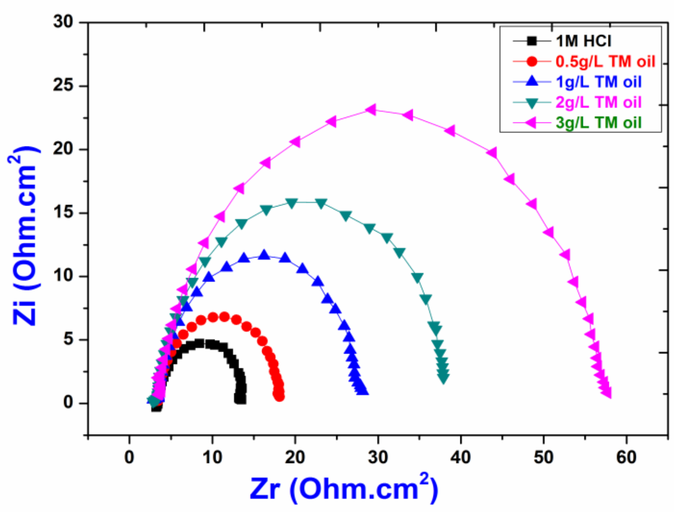

Fig.4. Nyquist diagrams of steel in the absence and presence of *Thymus munbyanus* essential oil.

Table 5. Electrochemical parameters of mild steel in 1M HCl at various concentration of *Thymus munbyanus* essential oil.

Concentration (g/L)	R_t ($\Omega.cm^2$)	f_{max} (Hz)	C_{dl}($\mu F.cm^2$)	E_{Rt}%
HCl 1M	12.24	111.40	11.26	--
0.5	18.24	101.20	8.34	32.89
1	29.45	87.45	6.18	58.44
2	37.8	68.50	5.93	67.62
3	59.4	52.70	4.90	79.39

From Table 5, it is clear that the R_t values increase with inhibitor concentration and the inhibition efficiency (E_{Rt}) reaches 79.39% at 3g/L TM. In other hand, the presence of *T. munbyanus* oil is accompanied by the increase of the R_t value in 1M HCl medium confirming a charge transfer process mainly controlling the corrosion of mild steel. The double layer capacitance values are also brought down to the maximum extent in the presence of inhibitor and the decrease in the values of C_{dl} follows the order similar to that obtained for I_{corr}. The decrease in C_{dl} is due to the essential oil adsorption on the metal surface leading to the formation of film or complex from acidic medium. It should be noted that the increase of the R_t value with inhibitor concentration leading to an increase in the corrosion inhibition efficiency. However, the EIS results (Fig. 5) of these loops capacitive are simulated by the equivalent circuit to pure electric models that could verify or rule out mechanistic models and enable the calculation of numerical values corresponding to the physical and/or chemical properties of the electrochemical system under investigation [28].

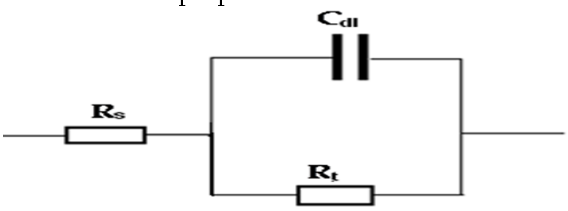

Fig.5. Equivalent circuit used to fit the EIS data of mild steel in 1M HCl without and with *Thymus munbyanus* essential oil.

4.1.5. Roughness measurements

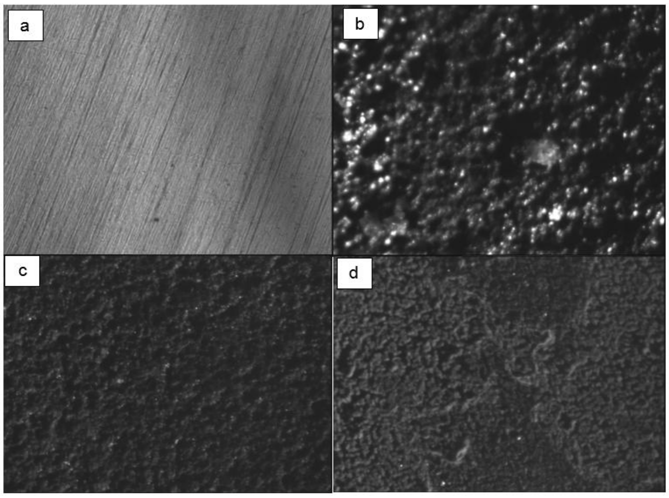

Fig.6. (a) Mild steel after polishing, (b) mild steel after immersion in 1M HCl (c,d) mild steel after immersion in 1M HCl with 2g/l and 3g/l of *T. munbyanus* essential oil respectively.

The surface roughness of the mild steel is evaluated by optical microscope before and after corrosion in the absence and presence of *Thymus munbyanus* essential oil at different concentrations (0.5-3g/L). It is clearly seen from the Fig. 6 that the steel sample shows a rough surface due to acid corrosion. However, the presence of 3g/L of essential oil retarded the corrosion and the surface of the inhibited mild steel specimen gets smoothened as shown in Fig.6 (c and d). The decrease in roughness can be very well understand to be due to the formation of adsorbed protective film of components from *T. munbyanus* oil on the metal steel surface by the process of physical adsorption

4.1.6. Mechanism of inhibition properties

The essential oil of *T. munbyanus* is dominated by phenolic compounds. These compounds contain Oxygen atoms in functional groups which meets the general characteristics of typical corrosion inhibitors. Accordingly, the inhibitive action of this essential oil could be attributed to the adsorption of its aromatic components on the mild steel surface. Thus, it is reasonable to deduce that carvacrol, □-terpinene and thymol exhibit the performance inhibition. In acidic medium, these constituents exist either as neutral molecules or in the protonated form. Two modes of adsorption are considered on the metal surface in acid media. In one mode, the neutral molecules may be adsorbed on the mild steel surface through the chemisorption mechanism, involving the displacement of water molecules from the mild steel surface and the sharing electrons between the oxygen atoms and iron. The inhibitor molecules can also adsorb on the mild steel surface on the basis of donor–acceptor interactions between their vacant d-orbitals and π-electrons of surface iron. In second mode, since it is well known that it is difficult for the protonated molecules to approach the positively charged mild steel surface due to the electrostatic repulsion. Since Cl^- have a smaller degree of hydration, they could bring excess negative charges in the vicinity of the interface and favor more adsorption of the positively charged inhibitor molecules, the protonated inhibitors adsorb through electrostatic interactions between the positively charged molecules and the negatively charged metal surface [29].

5. CONCLUSIONS

The essential oil of *Thymus munbyanus* Boiss & Reut obtained by hydrodistillation was analyzed by GC and GC/MS allowed the identification of 29 main components which accounted (97.8%) of the total amount. The essential oil is dominated by oxygenated monoterpenes (48.8%) and hydrocarbon monoterpenes (46.5%).

The *Thymus munbyanus* Boiss & Reut essential oil act as effective corrosion inhibitors for mild steel in 1M HCl, their inhibition efficiency related with concentration and chemical composition, at a concentration of 3g/L TM showed the inhibition efficiency reaches 80.66%. The inhibition action of this oil can be attributed to the adsorption of phenolic compounds such as carvacrol (31.7%), □-terpinene (21.9%), p-cymene (14.7%) and thymol (7.6%). The results of potentiodynamic measurements revealed clearly that *T. munbyanus oil* is a good cathodic inhibitor for mild steel corrosion in 1M HCl. The results of EIS measurements indicated that the corrosion of steel is mainly controlled by the charge transfer process. For loss measurements, it is clear that inhibition efficiency values increased with the increasing of essential oil concentration.

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