

Inhibitive Action of Capparis Spinosa Extract on the Corrosion of Carbon Steel in an Aqueous Medium of Hydrochloric Acid

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Abstract: Capparidaceae (*Capparis spinosa*), is a common perennial shrub and woody plant, typically Mediterranean, largely used in folk medicine in the Mediterranean countries including Morocco. The effect of Capparis Spinosa (CSE) on the corrosion inhibition of carbon steel in 1 M hydrochloric acid (HCl) solution was evaluated by several analytical methods, among these are weight loss method, potentiodynamic polarization and impedance spectroscopy (EIS). Results showed that CSE inhibits the corrosion of steel and the inhibition is more efficient at high concentration of CSE. Results also showed that, the inhibition decrease at higher temperature. Potentiodynamic polarization studies clearly reveal that CSE acts as a cathodic inhibitor. The adsorption of Capparis Spinosa on carbon steel was found to obey the Langmuir adsorption isotherm. The activation energies and enthalpies of the corrosion process of carbon steel in acidic medium of CSE were also calculated.

Keywords: Inhibition; Carbon steel; Polarisation; Capparis Spinosa extract; Adsorption.

1. INTRODUCTION

Capparis Spinosa known traditionally in Morocco as Al-Kabara (CSE), is a common perennial shrub with medicinal and aromatic properties. It belongs to the family *Capparidaceae*, it grows in the wild in the Mediterranean region like Morocco, Italy, Spain and other countries [1]. The first recorded medical application for Capparis was by the Sumerians in 2000 BC. The ancient Romans also used the plant for the same purpose. All of the roots, stems and leaves of *spinosa* are used as food [2]. *Capparis spinosa* has been also known to have anti-inflammatory [3], anti-oxidative [4,5], anti-hepatotoxic [6], anti-bacterial [7] antidiabetic activities [8]. The medical effectiveness of this plant was related to the fact that the plant contains a significant amount of antioxidants bioflavonoids and Vitamine C. The importance of these compounds is related to their biological and free radical scavenger activities. The presence of these antioxidants in the extract of CSE makes it an attractive source for natural metal corrosion inhibitor.

The technology of metal corrosion inhibitor has recently received a considerable amount of attention [9]. Plant extracts considered to-be excellent for

corrosion metals against acidic media [10-22]. Plant extracts are low-cost and biodegradable. These values make plant extracts valuable in both economic and environmental point of view. In our labs we did several studies for using extracts for corrosion inhibition against acidic media. One of those studies Chamomile extract [23], Argan oil [24, 25], Argan extract [26], Verbena extract [27], *Thymus capitatus* [28,29], *Thymus oil* [30,31], *Artemisia* [32-33], *Hibiscus sabdariffa* [34], *Citrus paradise* [35], *Jojoba oil* [36], *Lavender oil* [37], *Pennyroyal Mint oil* [38], *Oxandra asbeckii* [39] and *Piperanine* [40] All of those previous studies gave excellent results as corrosion inhibitors for metals in acidic medium. This work aimed to study the use of Capparis Spinosa extract as carbon steel corrosion inhibitor in 1 M HCl solution.

2. MATERIALS AND METHODS

2.1. Solutions Preparation

The aerial parts of Capparis Spinosa (CSE) were obtained from a special production field in the region of Souss Massa Valley (Morocco). A stock solution of Capparis Spinosa extract was prepared as follows: A known weight of dried and pulp fruits of Capparis Spinosa plant were crushed in a blender and soaked for 24 h at room temperature in 1 M HCl solution. After solution preparation and filtration, the solution kept as stock solution. All corrosion measurements were done in triplicate to assure accuracy.

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2.2. Materials

A carbon steel with a composition (Euronorm: C35E carbon steel and US specification: SAE 1035) with a chemical composition (in wt%) of 0.370 % C, 0.230 % Si, 0.680 % Mn, 0.016 % S, 0.077 % Cr, 0.011 % Ti, 0.059 % Ni, 0.009 % Co, 0.160 % Cu and the remainder iron (Fe) was used for the experiment.

2.3. Gravimetric, Polarization and Impedance Spectroscopy Measurements

2.3.1. Gravimetric Analysis

The carbon steel used for experiment was rectangular with a dimension (2cmx 2cm x 0.08 cm) and was placed in a solution of 1 M HCl at different concentration of *Cappars Spinosa* for 6 h. Gravimetric analysis were done using a glass cell with a controlled cooling condenser. The specimen was abraded with glass paper of different grades and after that washed with ethanol and distilled water.

2.3.2. Potentiodynamic Polarization

Polarization measurements were carried out using Volta lab (PGZ 100) potentiostat that was controlled by software model (Voltmaster 4) under static condition. This potentiostat is connected to a cell with three electrode thermostats with double wall (Tacussel Standard CEC/TH). The working electrode is a rectangular disk from carbon steel. A saturated calomel electrode (SCE) and a platinum electrode were used, respectively, as reference and auxiliary electrode. All potentials were referred to this reference electrode. Each reading has a 30 min of stabilization time to have a stable value for E_{corr} . The electrochemical was studied for both inhibited and uninhibited and were recorded for anodic and cathodic potentiodynamic polarization curves. The experiments were done at scan range of potential -800 to -200 mV/SCE with 1mV/s scan rate. To obtain the corrosion current densities (I_{corr}) a segment of extrapolation from by Tafel slopes for both cathodic and anodic were taken.

2.3.3. Electrochemical Impedance Spectroscopy (EIS)

The electrochemical impedance spectroscopy (EIS) experiments were done in the frequency range of 100 kHz to 0.1 Hz using open circuit potential, of 10 points /decade, after 30 min of acid immersion, by applying 10 mV ac voltage peak-to-peak. The best semicircle used to fit through the data points in the Nyquist plot using a non-linear least square fit with the interaction with the x-axis.

3. RESULTS AND DISCUSSION

3.1. Polarization Results

The effect of different concentration of *Spinosa* on corrosion is shown in Figure 1. Extrapolation of Tafel straight line shown in Figure 1, which helps us to calculate the values of electrochemical parameters, such as corrosion potential (E_{corr}), cathodic Tafel slopes (b_c), corrosion current density (I_{corr}). All these value are summarized in Table 1.

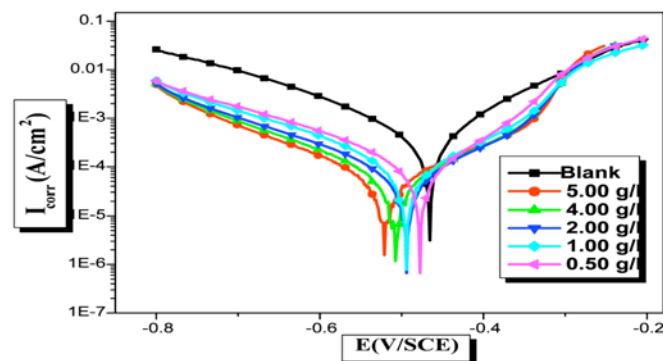


Figure 1: Summary of the potentiodynamic polarization of C38 steel at different concentration.

The inhibition efficiencies were calculated from I_{corr} values according to equation 1:

$$E_i \% = \frac{I_{corr} - I'_{corr}}{I_{corr}} \times 100 \quad (1)$$

where I_{corr} and I'_{corr} are uninhibited and inhibited corrosion current densities, respectively.

Careful evaluation of polarization curves and electrochemical parameter indicates that the inhibition efficiency increased, and the corrosion current density decreased when the concentration of the inhibitor is increased. The results indicate that, the adsorption of inhibitor molecules on the carbon steel surface increase with increasing the inhibitor concentration.

Table 1: Electrochemical Parameters of C38 Steel at Various Concentrations of CSE in 1M HCl and Corresponding Inhibition Efficiency

Inhibitor	$-E_{corr}$ (mV/SCE)	I_{corr} ($\mu\text{A}/\text{cm}^2$)	$-b_c$ (mV/dec)	E_i (%)
Blank	469	588	168	-
5.0 g/l	520	40	165	93.19
4.0 g/l	507	62	156	89.45
2.0 g/l	495	72	149	87.75
1.0 g/l	494	121	142	79.42
0.5 g/l	478	134	140	77.21

From the above table we can see the slopes of the cathodic Tafel lines b_c changed with increasing inhibitor concentration, which effect the presence of the **CSE** on the kinetics of hydrogen evolution and this shift E_{corr} towards more cathodic values. This shift in E_{corr} values towards more negative potential. This indicat that the inhibitor is cathodic [41,42]. The inhibition efficiency of *Capparis Spinosa* was observed at 5g/L.

3.2. Electrochemical Impedance Spectroscopy Measurements

The Nyquist representations of impedance behavior of carbon steel in 1M HCl solution in the absence and the presence of *Capparis Spinosa* at different concentrations plotted at open circuit potential (E_{corr}) at 298 K after 30 min of contact time is shown in Figure 2. The diameter of Nyquist plots increased when increasing concentration of *Capparis Spinosa*, and this cause formation of inhibition film on the surface. It is also clear that the impedance diagrams show depressed semicircles at the center under the real axis, generally referred to the frequency dispersion of interfacial impedance due to roughness, inhomogeneity of the solid surfaces and adsorption of inhibitor [43,44].

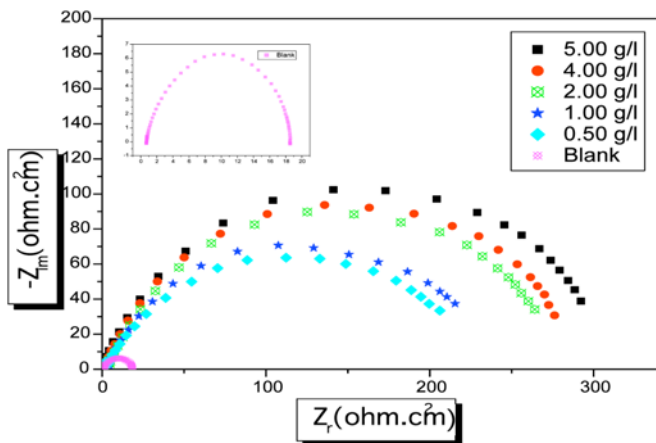


Figure 2: Nyquist plots for carbon steel in 1 M HCl with different concentrations of **CSE**.

To calculate inhibition efficiency using the EIS measurements, eq. 2 was used.

$$E_{Rt} \% = \frac{(R_t - R_t^0)}{R_t} \times 100 \tag{2}$$

were R_t and R_t^0 are the charge transfer resistances in inhibited and uninhibited solutions respectively.

The values of the polarization resistance were calculated by subtracting the high frequency

intersection from the low-frequency intersection [45]. The double-layer capacitance (C_{dl}) and the frequency at which the imaginary component of the impedance is maximal ($-Z_{max}$) are found using eq.3.

$$C_{dl} = \frac{1}{2\pi \cdot f_{max} \cdot R_t} \tag{3}$$

with C_{dl} : Double layer capacitance ($\mu F \cdot cm^{-2}$); f_{max} : maximum frequency (Hz) and R_t : Charge transfer resistance ($\Omega \cdot cm^2$).

The values of charge transfer resistance R_t , double layer capacitance C_{dl} derived from Nyquist plots and inhibition efficiency E_{Rt} , for the corrosion of carbon steel in 1M HCl with different concentration of inhibitors are listed in Table 2. It can be seen that the presence of *Capparis Spinosa* enhances the values of R_t and reduces the C_{dl} values. The decrease in the C_{dl} was a result of the decrease of the local dielectric constant and/or from the increase of thickness of the electrical double layer [46] indicating that, *Capparis Spinosa* extract adsorbed at the metal surface preventing metal/solution interface.

Table 2: Parametrs of the Electrochemical Impedance of Corrosion of Steel in Acid Medium at Various Concentrations of CSE

Inhibitor	Conc. (g/l)	$R_{ct}(\Omega \cdot cm^2)$	$C_{dl}(\mu F/cm^2)$	$E_{RT} (\%)$
Blank	0	18	221	-
CSE	5.0	306	20.81	94.12
	4.0	284	22.43	90.66
	2.0	276	23.08	87.48
	1.0	232	27.45	79.20
	0.5	222	28.69	77.01

3.3. Adsorption isotherm

Adsorption isotherm was used to understand the interaction between inhibitor and the electrode surface. The adsorption isotherm was best fit with Langmuir isotherm using eqs 4-5 [47].

$$\frac{C}{\theta} = \frac{1}{K} + C \tag{4}$$

$$K = \frac{1}{55.5} \exp\left(-\frac{\Delta G_{ads}}{RT}\right) \tag{5}$$

where C is the inhibitor concentration, θ the fraction of the surface covered determined by $E/100$, k the

equilibrium constant, ΔG_{ads}° is the standard free energy of adsorption reaction, R is the universal gas constant, T is the thermodynamic temperature and the value of 55.5 is the concentration of water in the solution in mol/L. Fig. 14 shows the dependence of the ratio C/θ as function of C .

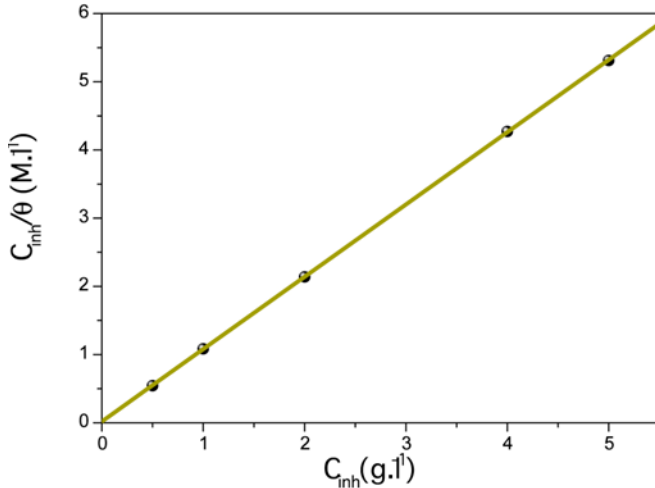


Figure 3: Langmuir adsorption isotherm of **CSE** on the steel surface at 298K.

From Figure 3 we obtained almost straight line with correlation value close to 1. The thermodynamic constants obtained from Figure 3 are summarized in Table 3.

Table 3: Parameters of Thermodynamic of the Adsorption of CSE in 1.0 M HCl on the Carbon Steel at 298K

Inhibitor	Slope	K_{ads} (M^{-1})	R^2	ΔG_{ads}° (kJ/mol)
CSE	1.06	50.84	0.99	-19.675

The value ΔG_{ads}° is calculated as $-19.675 \text{ kJ mol}^{-1}$. From the negative sign of ΔG_{ads}° which indicates spontaneity of the adsorption process and the stability of the adsorbed layer on the electrode surface [48, 49].

Generally, values of ΔG_{ads}° up to -20 kJ mol^{-1} or lower are associated with an electrostatic interaction between charged molecules and charged metal surface (physical adsorption); while the values around -40 kJ/mol or lower involves charge sharing or transfer from the inhibitor molecules to the metal surface to form a co-ordinate covalent bond (chemical adsorption) [50]. In the present work, the value of ΔG_{ads}° is found to be around -20 kJ mol^{-1} ; means that the adsorption mechanism of Capparis Spinosa on carbon steel surface is mainly the physisorption.

3.4. Effect of Temperature

The study of temperatures effect on the corrosion behavior of carbon steel using polarization methods in the range of 298–328 K in the absence and the presence of CSE at 5 g/l in 1M HCl were studied and shown in Figures 4 and 5.

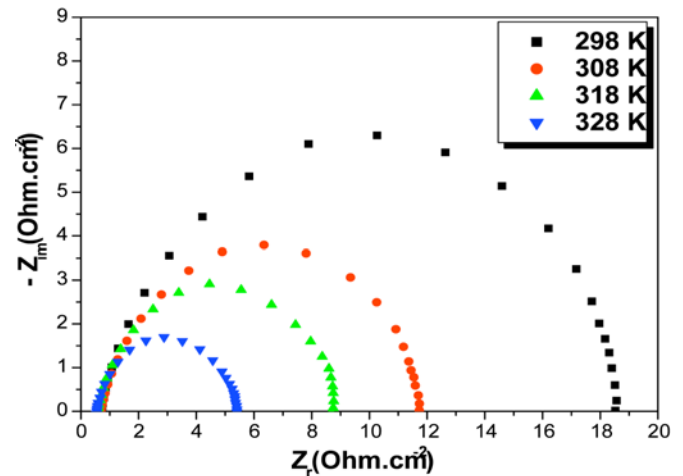


Figure 4: Nyquist diagrams for C38 steel in 1 M HCl at different temperatures.

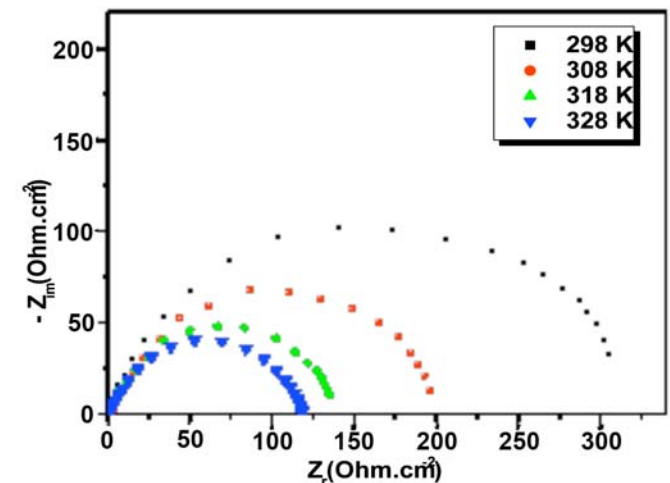


Figure 5: Nyquist diagrams for C38 steel in 1 M HCl + 5g/l of CSE at different temperatures.

In the studied temperature range (298–328 K) both the R_{ct} values and the inhibition efficiency decrease with increasing temperature in uninhibited and inhibited solutions. The R_{ct} value of C38 steel increases more rapidly with temperature in the presence of the inhibitor; these results confirm that Capparis Spinosa acts as an efficient inhibitor in the range of temperature studied.

The corrosion rate is inversely proportional to R_t values and the parameters of of E_a , ΔH_a and ΔS_a were

estimated from the slopes of the straight lines in Figures 6 and 7.

Table 4: Thermodynamic Parameters for the Adsorption of CSE in 1 M HCl on the C38 Steel at Different Temperatures

Inhibitor	T (K)	R _t (Ω.cm ²)	C _{dl} (μF/cm ²)	E _{Rt} (%)
Blank	298	18	221	-
	308	11	229	-
	318	8	199	-
	328	5	201	-
CSE	298	306	21	94.12
	308	200	20	94.50
	318	135	18	94.07
	328	118	21	95.76

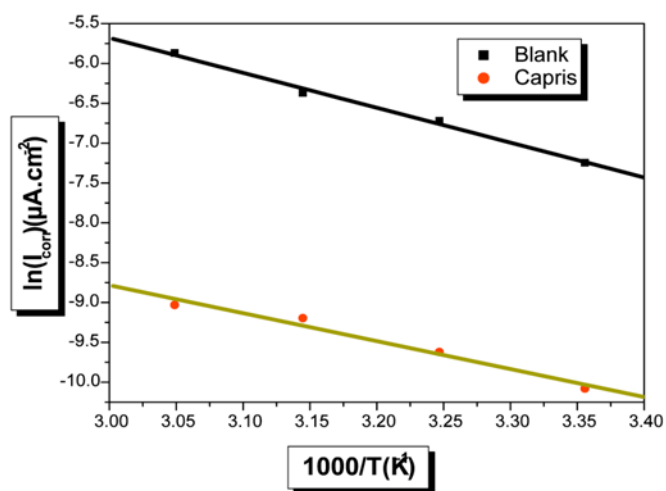


Figure 6: Arrhenius plots of steel in 1 M HCl with and without 5g/l of CSE.

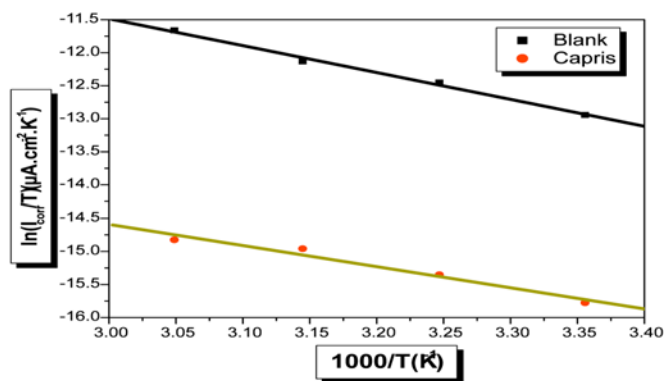


Figure 7: Arrhenius plots of steel in 1 M HCl with and without 5g/l of CSE.

Table 5: The Value of Activation Parameters E_a, ΔH_a, ΔS_a and ΔG_{ads} for Steel in 1M HCl in the Absence and Presence of 5g/l of CSE

Inhibitor	E _a (kJ/mol)	ΔH _a (kJ/mol)	ΔS _a (J/mol)	E _a -ΔH _a (KJ/mol)
Blank	36.39	33.79	-191.53	2.60
CSE	29.14	26.55	-239.06	2.60

The values of E_a from the solution having Capparis Spinosa is lower than the blank. Also, the positive signs of ΔH_a indicates that the endothermic nature of the Carbon steel dissolution process. The value of ΔS_a is lower for inhibited solution than that for the uninhibited solution. This phenomenon suggested that a decrease in randomness occurred on going from reactants to the activated complex.

4. CONCLUSION

There was a direct relation between inhibition efficiency and the concentration of Spinosa and it appeared mostly at 5 g/L. While increasing temperature decreased inhibition efficiency. The extracts of Capparis Spinosa in HCl acts as cathodic type inhibitor. The adsorption of the Capparis Spinosa extract is a spontaneous process as indicated by the negative value of the ΔG^o_{ads} indicates that and obeys the Langmuir isotherm model

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REFERENCES

- [1] Trombetta D, Occhiuto F, Perri D, Puglia C, Santagati NA, De Pasquale A, et al. Antiallergic and antihistaminic effect of two extracts of capparispinosa L. flowering buds. *Phytother Res.* 2005; 19: 29-33. <http://dx.doi.org/10.1002/ptr.1591>
- [2] Rodrigo M, Lazaro M, Alvarruiz A, Giner V. Composition of capers (*Capparis spinosa*): influence of cultivar. *J Food Sci.* 1992; 57: 1152-1154. <http://dx.doi.org/10.1111/j.1365-2621.1992.tb11286.x>
- [3] Issac Abraham SV, Palani A, Ramaswamy BR. Antiquorum sensing and antibiofilm potential of *capparis spinosa*. *Arch Med Res.* 2011; 8: 658-668. <http://dx.doi.org/10.1016/j.arcmed.2011.12.002>
- [4] Germano MP, De Pasquale R, D'Angelo. Evaluation of extracts and isolated fraction from *capparis spinosa* L. Buds

- as an antioxidant source. J Agric Food Chem. 2002; 27: 1168-1171.
<http://dx.doi.org/10.1021/jf010678d>
- [5] Tlili N, Khaldi A, Triki S. Phenolic compounds and vitamin antioxidants of caper (*capparis spinosa*). Plant Foods Human Nutr. 2010; 3: 260-265.
<http://dx.doi.org/10.1007/s11130-010-0180-6>
- [6] Aghel N, Rashidi I, Mombeini A. Hepatoprotective activity of *capparis spinosa* root bark against CCl₄ induced hepatic damage in mice. Iranian J Pharm Res. 2007; 4: 285- 290.
- [7] Boga C, Forlani L, Calienni R. On the antibacterial activity of roots of *capparis spinosa* L. Nat Prod Res. 2011; 4: 417-421.
<http://dx.doi.org/10.1080/14786419.2010.487189>
- [8] Huseini HF, Hasani-Rnjbar S, Nayebi N. *Capparis spinosa* L. (Caper) fruit extract in treatment of type 2 diabetic patients: A randomized double-blind placebo-controlled clinical trial. Complement Ther Med. 2013; 5: 447-452.
<http://dx.doi.org/10.1016/j.ctim.2013.07.003>
- [9] Uhlig HH, Revie RW. Corrosion and corrosion control, Wiley, NewYork, 1985.
- [10] Sastri VS. Green corrosion inhibitors. Theory and Practice, John Wiley & Sons: Hoboken, NJ; 1998.
- [11] Messaadia L, El Mouden IDO, Anejjar A, Messali M, Salghi R, Benali O, et al. Adsorption and corrosion inhibition of new synthesized Pyridazinium-Based ionic liquid on carbon steel in 0.5 M H₂SO₄. J Mater Environ Sci. 2015; 6(2): 598-606.
- [12] Anejjar A, Salghi R, Zarrouk A, Benali O, Zarrok H, Hammouti B, et al. Inhibition of carbon steel corrosion in 1 M HCl medium by potassium thiocyanate. J Assoc Arab Univers Bas Appl Sci. 2014; 15(1): 21-27.
<http://dx.doi.org/10.1016/j.jaubas.2013.06.004>
- [13] Ouici HB, Benali O, Harek Y, Larabi L, Hammouti B, Guendouzi A. Adsorption and inhibition effect of 5-phenyl-1,2,4-triazole-3-thione on C38 steel corrosion in 1 M HCl. Res Chem Intermed. 2015; 41: 4617-4634.
<http://dx.doi.org/10.1007/s11164-014-1556-2>
- [14] Mihit M, Bazzi L, Salghi R, Hammouti B, El Issami S, Ait Addi E. Some tetrazolic compounds as corrosion inhibitors for copper in nitric acid medium. Int Sci J Altern Ener Ecol. 2008, 62: 173-181.
- [15] Zarrok H, Zarrouk A, Hammouti B, Salghi R, Jama C, Bentiss F. Corrosion control of carbon steel in phosphoric acid by purpald-Weight loss, electrochemical and XPS studies. Corr Sci. 2012; 64: 243-252.
<http://dx.doi.org/10.1016/j.corsci.2012.07.018>
- [16] Senhaji B, Ben Hmamou D, Salghi R, Zarrouk A, Chebli B, Zarrok H, et al. *Asteriscus imbricatus* extracts: Antifungal activity and anticorrosion inhibition. Int J Electrochem Sci. 2013; 8: 6033-6046.
- [17] Zarrok H, Oudda H, Zarrouk A, Salghi R, Hammouti B, Bouachrine M. Weight loss measurement and theoretical study of new pyridazine compound as corrosion inhibitor for C38 Steel in hydrochloric acid Solution. Der Pharm Chem. 2011; 3: 576-590.
- [18] Belkhaouda M, Bammou L, Salghi R, Zarrouk A, Ben Hmamou D, Zarrok H, et al. Juniper oxycedrus extract as corrosion inhibitor for carbon steel in HCl medium. Der Pharma Lett. 2013; 5(2): 143-152.
- [19] Ben Hmamou D, Zarrouk A, Salghi R, Zarrok H, Ebenso EE, Hammouti B, et al. Experimental and theoretical studies of the adsorption and corrosion inhibition of 6-phenylpyridazine-3(2H)-thione on Carbon Steel in 2.0 M H₃PO₄ solution. Int J Electrochem Sci. 2014; 9(1): 120-138.
- [20] Afia L, Salghi R, Bammou L, Bazzi El, Hammouti B, Bazzi L, et al. Anti-corrosive properties of Argan oil on C38 steel in molar HCl solution. J Saudi Chem Soc. 2014; 18(1): 19-25.
<http://dx.doi.org/10.1016/j.jscs.2011.05.008>
- [21] El Mouden IDO, Anejjar A, Messali M, Salghi R, Ali Isma H, Hammouti B. The effect of new pyridazinium-based ionic liquid derivative as corrosion inhibitor for carbon steel in 1M HCl solution. Chem Sci Rev Lett. 2014; 3(11): 579-588.
- [22] Trabaneli G. Inhibitors an old remedy for a new challenge, Corrosion 1991; 47: 410-419.
<http://dx.doi.org/10.5006/1.3585271>
- [23] Ben Hmamou D, Salghi R, Zarrouk A, Messali M, Zarrok H, Errami M, et al. Inhibition of steel corrosion in hydrochloric acid solution by chamomile extract. Der Pharma Chemica. 2012; 4(4): 1496-1505.
- [24] Afia L, Salghi R, Benali O, Jodeh S, Al-Deyab SS, Hammouti B. Investigation of the corrosion inhibition behavior of C38 steel in hydrochloric acid solution by 2-Hydroxy-1- (2-hydroxy-4-sulfo-1-naphthylazo)-3-naphthoic acid. Trans Indian Inst Met. 2015; 68(4): 521-527.
<http://dx.doi.org/10.1007/s12666-014-0479-3>
- [25] Afia L, Salghi R, Bazzi El, Bazzi L, Errami M, Jbara O, et al. Testing natural compounds : *Argania spinosa* Kernels extract and cosmetic oil as ecofriendly inhibitors for steel corrosion in 1 M HCl. Int J Electrochem Sci. 2011; 6: 5918-5939.
- [26] Afia L, Salghi R, Bammou L, Bazzi LH, Hammouti B, Bazzi L. Application of Argan plant extract as green corrosion inhibitor for steel in 1M HCl. Acta Metall Sin. 2012; 25: 10-18.
- [27] Ben Hmamou D, Salghi R, Zarrouk A, Al-Deyab SS, Zarrok H, Hammouti B, et al. Verbena extract: An efficient inhibitor of C38 steel corrosion in hydrochloric acid. Int J Electrochem Sci. 2012; 7 (2012) 6234-6246.
- [28] Ouariachi El M, Paolini J, Bouyanzer A, Tomi P, Hammouti B, Salghi R, et al. Chemical composition and antioxidant activity of essential oils and solvent extracts of *Thymus capitatus* (L.) Hoffmanns & Link from Morocco. J Med Plants Res. 2011; 5: 5773- 5778.
- [29] Chetouani A, Hammouti B. Thyme as a naturally corrosion inhibitor for iron in hydrochloric acid solutions. Bull Electrochem. 2004; 20: 343-345.
- [30] Bouyanzer A, Hammouti B. Naturally occurring ginger as corrosion inhibitor for steel in molar hydrochloric acid at 353 K. Bull Electrochem. 2004; 20: 63-65.
- [31] Bammou L, Chebli B, Salghi R, Bazzi L, Hammouti B, Mihit M, et al. Thermodynamic properties of *Thymus saturoioides* essential oils as corrosion inhibitor of tinplate in 0.5 M HCl: Chemical characterization and electrochemical study. Green Chem Lett Rev. 2010; 3: 173-178.
<http://dx.doi.org/10.1080/17518251003660121>
- [32] Benabdellah M, Hammouti B, Benkaddour M, Bendahhou M, Aouniti A, Investigation of the inhibitive effect of triphenyltin 2-thiophene carboxylate on corrosion of steel in 2 M H₃PO₄ solutions, Appl Surf Sci. 2006; 252: 8341-8347.
<http://dx.doi.org/10.1016/j.apsusc.2005.11.037>
- [33] Bammou L, Mihit M, Salghi R, Bazzi L, Bouyanzer A, Hammouti B. Inhibition effect of natural artemisia oils towards tinplate corrosion in HCl solution: Chemical characterization and electrochemical study. Int J Electrochem Sci. 2011; 6: 1454-1467.
- [34] Ouachikh O, Bouyanzer A, Bouklah M, Desjobert Costa JM, Hammouti B, Majidi L. Application of essential oil of artemisia herba alba as green corrosion inhibitor for steel in 0.5M H₂SO₄. Surf Rev Lett. 2009; 16: 49-54.
<http://dx.doi.org/10.1142/S0218625X09012287>
- [35] Emeka EO. Corrosion inhibitive effect and adsorption behaviour of *Hibiscus Sabdariffa* extract on mild steel in acidic media. Portug Electrochim Acta 2008; 26: 303-314.
- [36] Olusegun AK, Oforka NC, Ebenso EE. The inhibition of mild steel corrosion in an acidic medium by the juice of citrus paradisi (Grapefruit). J Corros Sci Eng. 2004; 8: 1- 5.
- [37] Bouyanzer A, Hammouti B. A study of anti-corrosive effects of Artemisia oil on steel. Pigm & Resin Techn. 2004; 33: 287-292.
<http://dx.doi.org/10.1108/03699420410560489>

- [38] Zerga B, Sfaira M, Rais Z, Ebn Touhami M, Taleb M, Hammouti B, *et al.* Lavender oil as an ecofriendly inhibitor for mild steel in 1 M HCl. *Mater Tech.* 2009; 97: 297-305. <http://dx.doi.org/10.1051/mattech/2009045>
- [39] Bouyanzer A, Hammouti B, Majidi L. Pennyroyal oil from *Mentha pulegium* as corrosion inhibitor for steel in 1 M HCl. *Mater Lett.* 2006; 60: 2840-2843. <http://dx.doi.org/10.1016/j.matlet.2006.01.103>
- [40] Lebrini M, Robert F, Lecante A, Roos C. Corrosion inhibition of C38 steel in 1M hydrochloric acid medium by alkaloids extract from *Oxandra asbeckii* plant. *Corros Sci.* 2011; 53: 687-695. <http://dx.doi.org/10.1016/j.corsci.2010.10.006>
- [41] Dahmani M, Al-Deyab SS, Et-Touhami A, Hammouti B, Bouyanzer A, Salghi R, *et al.* Investigation of piperanine as HCl ecofriendly corrosion inhibitors for C38 steel. *Int J Electrochem Sci.* 2012; 7: 2513-2522.
- [42] Anejjar A, Salghi R, Zarrouk A, Zarrok H, Benali O, Hammouti B, *et al.* Investigation of inhibition by 6-bromo-3-nitroso-2- phenylimidazol [1,2- α] pyridine of the corrosion of C38 steel in 1 M HCl. *Res Chem Intermed.* 2015; 41: 913-925. <http://dx.doi.org/10.1007/s11164-013-1244-7>
- [43] Bentiss F, Traisnel M, Vezin H, Lagrenee M. Electrochemical study of substituted triazoles adsorption on mild steel. *Ind Eng Chem Res.* 2000; 39: 3732-3736. <http://dx.doi.org/10.1021/ie000043o>
- [44] Ozcan M, Solmaz R, Kardas G, Dehri I. Adsorption properties of barbiturates as green corrosion inhibitors on mild steel in phosphoric acid. *Colloid Surf A.* 2008; 325: 57-63. <http://dx.doi.org/10.1016/j.colsurfa.2008.04.031>
- [45] Li X, Deng S, Fu H, Li T. Adsorption and inhibition effect of 6-benzylaminopurine on cold rolled steel in 1.0 M HCl. *Electrochim Acta* 2009; 54: 4089-4098. <http://dx.doi.org/10.1016/j.electacta.2009.02.084>
- [46] Benabdellah M, Yahyi A, Dafali A, Aouniti A, Hammouti B, Ettouhami A. Corrosion inhibition of steel in molar HCl by Triphenyltin2-Thiophene carboxylate. *Arabian J Chem.* 2011; 4: 343-347 [46] Bosch RW, Hubrecht J, Bogaerts WF, Syrett BC. *Corrosion.* 2001; 57: 60-70.
- [47] Abdullahi M, Farzam M, Irannejad A. A schiff base compound as effective corrosion inhibitor for carbon steel AISI 1018 in NaCl 3.5% media. *Researcher* 2014; 6(10): 71-77.
- [48] Aljourani J, Raeissi K, Golozar MA. Benzimidazole and its derivatives as corrosion inhibitors for mild steel in 1M HCl solution. *Corros Sci.* 2009; 51: 1836-1843. <http://dx.doi.org/10.1016/j.corsci.2009.05.011>
- [49] Bousskri A, Anejjar A, Messali M, Salghi R, Benali O, Karzazi Y, *et al.* Corrosion inhibition of carbon steel in aggressive acidic media with 1-(2-(4-chlorophenyl)-2-oxoethyl)pyridazinium bromide, *J Molec Liquids* 2015; 211: 1000-1008. <http://dx.doi.org/10.1016/j.molliq.2015.08.038>
- [50] Ben Hmamou D, Salghi R, Zarrouk A, Zarrok H, Touzani R, Hammouti B, *et al.* Investigation of corrosion inhibition of carbon steel in 0.5 M H₂SO₄ by new bipyrazole derivative using experimental and theoretical approaches. *J Environ Chem Eng.* 2015; 3: 2031-2041. <http://dx.doi.org/10.1016/j.jece.2015.03.018>

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