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Study of jojoba vegetable oil as inhibitor of carbon steel C38 corrosion in different acidic media

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Abstract
This work reports the use of a new kind of metal corrosion inhibitors called green inhibitors. The aim of this study is the evaluation of inhibitor efficiency of an oil extracted from the jojoba plant against the corrosion of C38 carbon steel in HCl (1M), H_3PO_4 (0.5 M) and H_2SO_4 (0.5M) media, using mass loss measurement and electrochemical methods. Gravimetric and electrochemical studies show that the addition of jojoba oil in the three media causes a decrease in corrosion current density and therefore a decrease in the rate of corrosion of steel C38. The inhibitor efficiency of the oil increases with the increase in the concentration of inhibitor. The highest efficiency of the employed inhibitor is found at 3 g/L concentration. Jojoba oil acts as a mixed inhibitor in HCl(1M) medium. In H_3PO_4 (0.5 M) and H_2SO_4 (0.5 M) media, the inhibitor is anodic. Its efficiency is optimum in 1M HCl medium instead in H_2SO_4 0.5M. This is probably because the SO_4^{2-} ions adsorb with higher rate than the Cl_- ions on the metallic surface, thus occupying more active sites on the surface and leaving enable fewer sites.

Keywords: Corrosion inhibitor, Jojoba oil, Steel, Acid solution, Weight loss

1. Introduction
The phenomenon of corrosion is an interface problem between a metal and an aggressive environment liquid or gaseous leading to a destruction of metallic materials. This phenomenon took today a considerable importance in view of the increasing use of metals and alloys in modern life. It is a very common in industries used the acids such as acid pickling, industrial cleaning. To increase the durability of metals, several techniques of protection appropriate against corrosion were used (application of coating, electrochemical protection and use of inhibitors ...).The use of inhibitors is one of the best options of protecting metals against corrosion. The acids damage the materials under treatment and in this kind of situation; various synthetic organic and inorganic compounds have been used as inhibitors to reduce the corrosive property of acids [1-3]. However, most of these inhibitors are toxic to the environment and human. They are expensive and present dangerous effects. These inhibitors can cause temporary or permanent damage to the organs such as the kidneys or liver system or disrupt the enzyme system in the body [4]. This has prompted the search for green corrosion inhibitors.Green corrosion inhibitors are biodegradable and donot contain heavy metals or other toxic compounds. They are used to protect metals in the acidic environment to replace toxic chemicals currently used [5]. In industrial processes using phosphoric acid especially in fertilizer production, the protection of metals has been the subject of much interest. To minimize the problem of corrosion in this environment some investigations have also been done using synthetic inhibitors [6-8], but little works appear to have been done using naturally occurring substances in phosphoric acid as corrosion inhibitors [9].Some research groups have reported the successful use of naturally occurring substances to inhibit the corrosion of metals in acidic environment. We can cite: eucalyptus oil [10],

anise extract [11,12], mentha spicata essential oil [13], musa paradisiac peel extract [14], warionia saharea essential oil [15], pulicaria mauritanica [16], essential oil of pimpinella anisum L. [17], bamboo leaf extract [18], essential oil of salvia aucheri [19], carob seed [20], chenopodium ambrorsioides extract [21], spondias mombin L. [22], etc, all naturals product used in acidic medium showed a good inhibitory efficiency. Futheremor, excellent results were obtained using of Jojoba oil as inhibitor of pure iron in HCl solutions [23]. In this paper, the corrosion inhibitor of jojoba oil on C38 steel in different acid media was investigated by free potential, potentiodynamic polarization, chronoamperometry and weight loss techniques.

2. Experimental

2.1. *Materials preparation*

The material used in this study is a C38 carbon steel 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 rest iron (Fe). Prior to all measurements, the C38 carbon steel samples were polished with different emery papers up to 2000 grade for removing metal oxides, rinsed with distilled water, and dried at room temperature before introducing it directly into the cell.

The aggressive solutions H_3PO_4 (0.5M), H_2SO_4 (0.5M) and HCl (1M) were prepared by dilution of analytical grade acid (86% H_3PO_4, 96% H_2SO_4, 37% HCl) with distilled water. The corrosion inhibition solution was prepared by dissolving natural jojoba oil in these aggressive solutions using 3 g/L as the concentration of inhibitor.

2.2 *Methods*

2.2.1. Electrochemical measurements

The electrochemical study was done with a potentiostat PGZ 301 controlled by a PC and supported by Voltamaster 4.0 software. This potentiostat connected to a cell with three electrodes. The working electrode was carbon steel with the surface area of 1 cm^2.

A saturated calomel electrode (SCE) was used as a reference. All potentials were given with reference to this electrode. The counter electrode was a platinum plate of surface area of 1 cm^2.

For polarization curves, the working electrode was immersed in a test solution without and with different concentrations of jojoba oil during 60 min until a steady state opens circuit potential (Eocp) was obtained. The chronoamperometry measurements were carried out at 0.1V/SCE. The electrochemical measurements were recorded from -1000 to 500 mV/SCE. The inhibition efficiency E (%) is calculated following this equation (1):

$$\boldsymbol{E}\% = \frac{\boldsymbol{i}^{\mathbf{0}}_{\boldsymbol{corr}} - \boldsymbol{i}_{\boldsymbol{corr}}}{\boldsymbol{i}^{\mathbf{0}}_{\boldsymbol{corr}}} \times \mathbf{100} \quad (\mathbf{1})$$

Where $\boldsymbol{i}^{\mathbf{0}}_{\boldsymbol{corr}}$ and $\boldsymbol{i}_{\boldsymbol{corr}}$ are the uninhibited and inhibited corrosion current densities, respectively.

2.2.2. Weight loss measurements

The effect of addition of jojoba oil tested on the corrosion of C38 steel in H_3PO_4 (0.5M), H_2SO_4 (0.5M) and HCl (1M) solutions was studied by weight loss measurements after 7 days of immersion period. Such C38 carbon steel were abraded with fine emery paper, rinsed with distilled water, and dried before being weighted and immersed in the corrosive medium. The solution volume was 25 mL without and with the inhibitor at 3 g/L. After the corrosion test, the specimens of steel were carefully washed with distilled water, dried and then weighted. The weight loss, (in grams), was taken as the difference in the weight of the steel coupons before and after immersion in the test solutions and the weight loss was calculated. The corrosion rate ($\boldsymbol{W}$) and inhibition efficiency E (%) were calculated according to the Eqs. (2) and (3) respectively:

$$\boldsymbol{W} = \frac{\Delta m}{S.t} \qquad \mathbf{(2)}$$

$$\boldsymbol{E}\% = (\,\mathbf{1} - \frac{\boldsymbol{W}_{\boldsymbol{inh}}}{\boldsymbol{W}_{\mathbf{0}}}) \times \mathbf{100} \quad (\mathbf{3})$$

where Δm (mg) is the specimen weight before and after immersion in the tested solution, W_0 and W_{inh} are the values of corrosion weight losses (mg/cm^2/day) of steel in uninhibited and inhibited solutions, respectively, S is the area of the steel specimen (cm^2) and t is the exposure time (days).

3. Results and discussion

3.1. Electrochemical measurements

To estimate the effect of the inhibitor on the anodic and cathodic partial reactions, electrochemical measurements were carried out in the potential range of - 1000 mV to +500 mV relative to the saturated calomel electrode.

3.1.1. *Electrochemical behavior of C38 in HCl (1M)*

Figure 1 shows the evolution of the open circuit potential during an hour of immersion of steel in the absence and the presence of jojoba oil (0 and 3 g / L) in HCl (1M) medium.

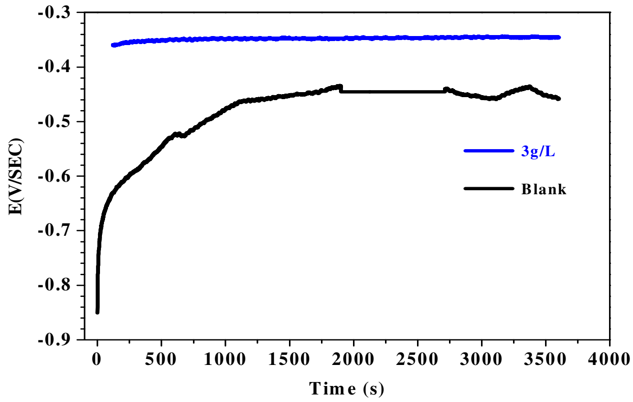

Figure 1: Evolution of free potential depending on the immersion time for C38 steel with and without inhibitor in HCl (1M)

As it can be observed in figure 1, in the absence of inhibitor, the corrosion potential (E_{corr}) tends to stabilize at a value of -0.453 V / SCE after 1 hour of immersion. The presence of jojoba oil influences the value of the free potential, moving the free potential towards less negative values. These results suggest that the addition of the oil induces an inhibition effect of steel in HCl medium. This ennoblement of free potential indicates a recovery of the steel surface with products or with some compounds of the green inhibitor, which decreases the rate of corrosion. Figure 2 shows polarization curves for C38 steel in HCl (1M) medium with and without the jojoba oil.

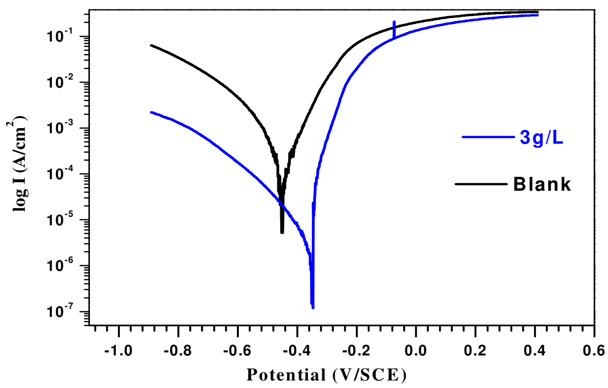

Figure 2: Polarization plots of C38 steel with and without inhibitor in HCl (1M) medium

These curves show that the anodic and cathodic reactions are affected by the addition of the inhibitor. Indeed, in additional of the displacement of free potential to more noble values, the addition of the inhibitor solution in HCl 1M induces the decrease of the cathodic and anodic current. Jojoba oil acts as a mixed inhibitor in HCl medium (1M).

Table 1 contains values of electrochemical parameters determined from the polarization curves; the corrosion current density (I_{corr}), the corrosion potential (E_{corr}) and corrosion-inhibiting efficiency E (%).

Table1: Electrochemical parameters determined for C38 steel in HCl 1M solution

Concentration (g/L)	E_{corr} (mV/SCE)	I_{corr} (mA/cm^2)	E%
0	-453	1	-
3	-348	2.25 10^{-2}	98

The above data show that the corrosion current densities (I_{corr}) decrease in the presence of the oil and the efficiency reached to a value of 98% for the concentration of 3g /L.

3.1.2. *Electrochemical behavior of C38 steel in phosphoric acid medium 0.5M*

Figure 3 shows the evolution of the free potential depending of the immersion period (1 hour) at different concentrations of jojoba oil in H_3PO_4 (0.5 M) medium. When jojoba oil is added to the solution of H_3PO_4 (0.5 M), an increase in potential is observed with the inhibitor concentration, indicating the formation of a protective film on the sample surface. The immediate response of the addition of jojoba oil in the electrolytic solution is ennoblement of free potential.

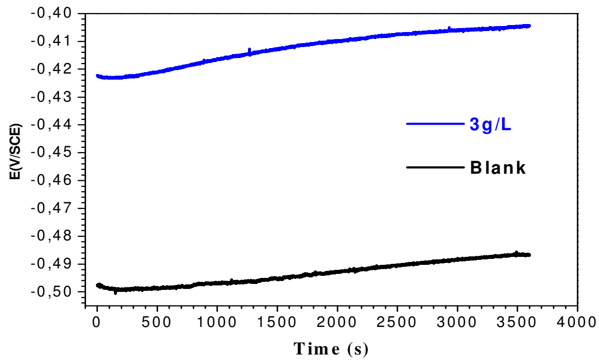

Figure 3: Evolution of the free potential for C38 steel with and without inhibitor in H_3PO_4 (0.5 M)

The effect of jojoba oil concentration on the anodic and cathodic polarization behavior of C38 steel in 0.5 M H_3PO_4 solution has been studied by polarization measurements and the recorded Tafel plots are shown in Figure4. The figure 4 shows polarization curves after 1 hour of the immersion of steel in this medium. Relevant data deduced from figures 4 are given in Table 2. The addition of the jojoba oil has a beneficial effect; it displaces the corrosion potential to anodic values compared to the result obtained in the absence of the inhibitor. Jojoba oil leads to reduction of anodic current densities of corrosion. The addition of jojoba oil in H_3PO_4 (0.5 M) decrease the current density when the corrosion inhibitor concentration increases. It acts as an anodic inhibitor.

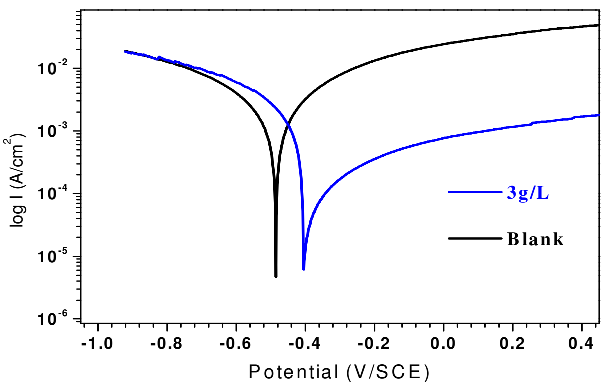

Figure 4: Polarization curves of C38 steel in H_3PO_4 (0.5 M) at 0 and 3g/L

Table2: Electrochemical parameters for C38 steel in H_3PO_4 (0.5 M) at various concentrations of jojoba oil

Concentration (g/L)	E_{corr}(mV/SCE)	I_{corr}(mA/cm^2)	E%
0	-486	6.7	-
3	-404	0.26	96

3.1.3. Electrochemical behavior of C38 steel in sulfuric acid medium 0.5M

The evolution of the free potential for a period of one hour of immersion of the material at 0 and 3g/L of jojoba oil in 0.5 M sulfuric acid medium is shown in Figure 5.
In the absence of jojoba oil, the evolution of the free potential versus time characterized the attack of the metal surface. In its presence, there is a displacement of corrosion potential to more noble values, which characterizes the formation of a protective layer on the metal surface.

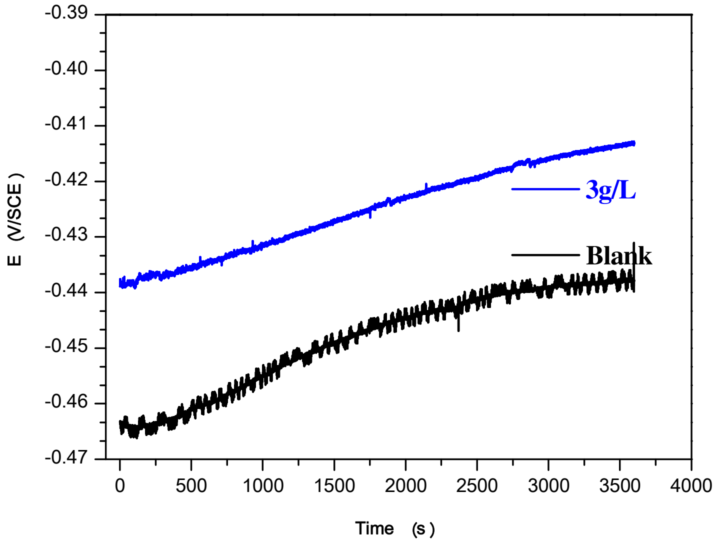

Figure 5. Evolution of the free potential in function of immersion time for C38 steel with and without inhibitor in H_2SO_4 (0.5 M)

The polarization curves for the C38 material realized in the electrolytic solution H_2SO_4 (0.5 M) in the absence and presence of jojoba oil are grouped in Figure 6. The electrochemical parameters (corrosion potential (E_{corr}), and corrosion current density (I_{corr})), determined from these experiments are reported in Table 3.

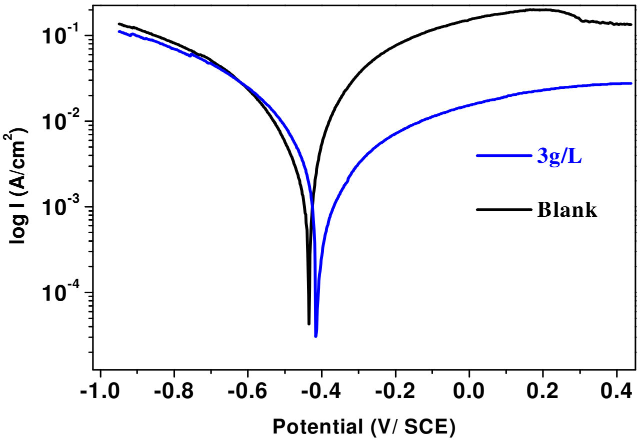

Figure 6. Polarization curves of C38 steel in H_2SO_4 (0.5 M) with and without jojoba oil

As illustrated in this figure, the corrosion potential is shifted to the anodic values in the presence of jojoba oil. The anodic current densities decrease with addition of the inhibitor, indicating that this behavior reflects the jojoba oil' ability to inhibit the corrosion of C38 steel in 0.5M H_2SO_4 solution via the adsorption of its molecules on anodic sites making a barrier between the environment and the metal material, and, consequently, the inhibitor act as anodic mode of inhibition. The examination of table 3 concluded that the values of current density of corrosion of C38 steel in H_2SO_4 medium with inhibitor are lower than that found without inhibitor. To the maximum concentration studied, the efficiency is 92%.

Table 3. Electrochemical parameters for C38 steel in H_2SO_4 (0.5 M)

Concentration (g/L)	E_{corr}(mV/SCE)	I_{corr}(mA/cm^2)	E%
0	-432	48	-
3	-415	4	92

3.2. *Chronoamperometric curves*

The chronoamperometric curves were obtained at potential equal to 0.1 V/SCE to follow the evolution of current for one hour of immersion of the C38 steel in the studied media (figure 7), in absence and in presence of 3 *g/L* of jojoba oil .

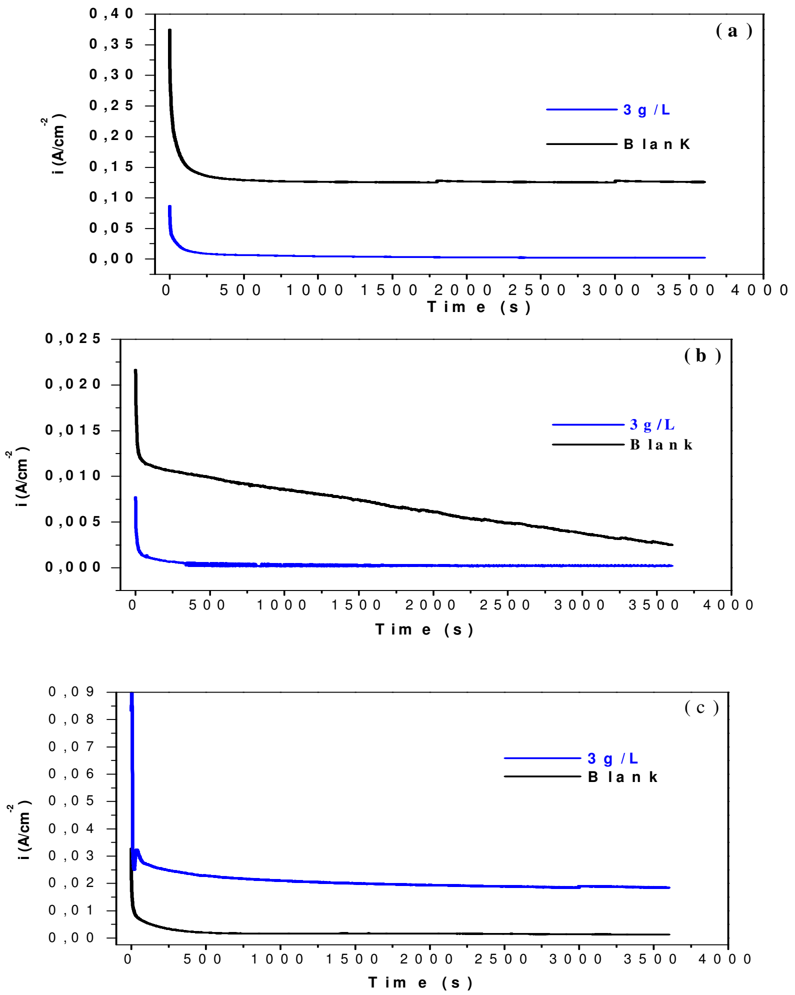

Figure 7. Chronoamperometric curves of C38 steel with and without inhibitor in the medium: (a) HCl (1M); (b) H_3PO_4 (0.5M); (c) H_2SO_4 (0.5M)

We notice a decrease of current with an increase of immersion time. It shows that the presence of jojoba oil induces a decrease in current. Moreover, the residual current measurement gives a good estimate of the efficiency of the barrier layer formed at the interface.

Table 4 shows the results determined from the chronoamperometric curves. These results indicate that the presence of 3g / L of jojoba oil, the corrosion current density decreases and the corrosion rate compared to in the absence of jojoba oil.

Table 4. Residual current, corrosion rate and efficiency at 0 and 3 g / L of the inhibitor determined from chronoamperometric curves

Medium	Concentration (g/L)	i_{corr}(mA/cm^2)	V_{corr} (mm/an)	E%
HCl (1M)	0	126.4	1478.9	-
	3	3.9	45.6	97
H_3PO_4 (0.5M)	0	3.8	44.5	-
	3	0.25	3.01	93
H_2SO_4 (0.5M)	0	20.6	241.02	-
	3	1.9	22.23	91

3.3. Inhibition efficiency based on weight loss measurements

The non-electrochemical technique of weight loss was done in order to determine the corrosion rate and percentage of inhibition. This physical measurement will provides direct result on how the corrosive environments affect the test samples and also to give the average corrosion rate during the experiment. Series of measures of weight loss was carried out in three corrosives media with and without addition of the inhibitor tested at different concentrations (0 and 3 g/L) for 7 days. The samples are weighted before (m_1) and then immersed in the corrosive solution. After one week of exposition, the samples were removed and dried in the oven and then weighted (m_2). The corrosion rates of the samples C38 steel (V_{corr}) were calculated from the determination of the weight loss (Δm).The values of percentage inhibition efficiency E_w (%) and corrosion rate (W) obtained from weight loss method without and with addition of inhibitor at 3g / L for 7 days are summarized in Table 5.

Table 5. Gravimetric results of C38 steel in various corrosive media at 0 and 3 g / L of jojoba oil

Medium	Concentration g/L	m_i (g)	m_f (g)	Δm (mg)	S (cm^2)	V_{corr} (mg/cm^2/j)	E%
HCl (1M)	0	3.1600	2.9853	174.7	4.96	5.03	-
	3	3.4079	3.3546	53.3	5.2	1.46	71
H_3PO_4 (0.5M)	0	3.1799	2.3234	856.5	4.96	24.67	-
	3	2.9125	2.6092	303.3	4.96	8.74	65
	0	3.2481	2.6089	639.2	5.44	16.79	-
(0.5M)	3	2.9903	2.7618	228.5	4.96	6.58	61

It is very clear that the jojoba oil inhibits the corrosion of C38 steel in the tree solutions, and the corrosion rate (W) decreases with the addition of inhibitor. This behavior can be attributed to the adsorption of components of the inhibitor on the C38 steel surface resulting in the blocking of the reaction sites, and protection of the C38 steel surface from the attack of the corrosion in the acid medium. Consequently, we can conclude that the jojoba oil is a good corrosion inhibitor for C38 steel in acidic media.

Conclusion

The work presented in this paper is a contribution to study the possibilities to use of a new type of corrosion inhibitors called green inhibitors.

The aim of this study consists to determine the inhibition efficiency of an oil extracted from the jojoba plant to the corrosion of C38 steel in HCl (1M) medium, H_3PO_4 (0.5 M) and H_2SO_4 (0.5M) by weight loss and electrochemical methods.

Gravimetric and electrochemical studies show that the addition of jojoba oil in the three media causes a decrease of corrosion current density and consequently a reduction of the corrosion rate of steel C38.

The inhibition efficiency of this oil depends on the nature of the acid. Jojoba oil acts as a mixed inhibitor in HCl (1M) medium**.** In H_3PO_4 (0.5 M) and H_2SO_4 (0.5 M) media, the inhibitor is anodic. It is most efficient in HCl 1M than H_2SO_4 (0.5M) medium, this is probably due to the fact that the ions SO_4^{2-} adsorb more than Cl^- ions on the metal surface, thus occupy more active sites on the surface medium and leave fewer sites to organic.

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