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Study of green corrosion inhibition for steel in 35g/l NaCl solution by sophora japonica Extract

Ouache Rachid[a,b], baira Fayçal [b], Benmoussa Mohammed Taher[c], Harkat Hassina[c]

[a] Laboratoire de physio-toxicologie, pathologie cellulaires et moléculaires-biomolécules (LPTPCMB),

[b] Département de science et technologie, faculté de technologie, université de BATNA 2, les allée 53 rue Constantine. Fésdis, Banta 05078, Algeria

[c]Faculté de Médecine, Département de Pharmacie, Université de Batna-2, Batna, Algérie; [b] Faculté des Sciences de la Matière, Département de Chimie, Université de Batna-1, Batna, Algérie

Email : f.baira@univ-batna2.dz

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Abstract

This work pertains to the study of inhibiting the corrosion of steel in a corrosive environment containing NaCl at a concentration of 35 g/l using the methanolic extract of the aerial part of Sophora japonica. The evaluation of the anticorrosive activity of steel in the NaCl 35g/l medium was conducted through gravimetric measurements and electrochemical tests. The results obtained showed that the corrosion inhibiting efficiency reaches a maximum value of approximately 91% after the addition of 1300 ppm of the methanolic extract of the aerial part of Sophora japonica.

Keys words: Sophora japonica, corrosion, steel, electrochemical, inhibition.

I-Introduction

The fundamental study of corrosion phenomena in wet and acidic environments is an area of materials science that includes both chemical and physical concepts. Corrosion results from the chemical or electrochemical action of an environment on metals and alloys. Corrosion phenomena take place on the surface of metallic materials exposed to a chemically aggressive environment [1].

The problem of corrosion has acquired great importance today, given the increasing use of metals and alloys in modern life. The study of corrosion lies at the crossroads of various fields: electrochemistry, solid-state physics, metallurgy, chemistry, physics, thermodynamics... In addition to its multidisciplinary scientific interest, it is a major industrial challenge [2].

From an economic point of view, corrosion is of paramount importance. It is estimated, for example, that every year a quarter of steel production is destroyed by corrosion, which corresponds to around 150 million tonnes/year, or 5 tonnes/second. These losses could be higher if corrosion protection were not available [3].

In this same context, our study consists of investigating the corrosion inhibition of ordinary steel by extracting the Sophora japonica tree in a 35g/l NaCl solution. Inhibition delays electrode reactions such as charge transfer or mass transport, and especially the corrosion process. It involves the use of chemical substances known as corrosion inhibitors [4,5]. Corrosion inhibitors are a novel means of combating corrosion of metallic materials. The most commonly used in corrosive environments are organic molecules than inorganic molecules [6,7,8,9].

Organic corrosion inhibitors can interfere with the anodic or cathodic reaction and form a protective barrier on the metal surface against corrosive agents [10,8,11]. Sophora japonica belongs to the Fabaceae family, which comprises some 52 species, nineteen varieties, and seven forms, widely distributed in Asia, Oceania, and the Pacific islands. Ranging from grasses to trees (*Sophora japonica L.*), its two subgenera are sophora (dehiscent fleshy fruit with incomplete mesocarp) and styphnolobium (indehiscent fleshy fruit with complete complete mesocarp) [12,13].

Sophora japonica is a 24-metre-high, 3.50-metre-circumference tree with the same strength of vegetation. The bright, cheerful, dark-green leaves are composed of a large number of leaflets, like those of the Robinier, pseudo ocasia, but smaller and firmer. The branches are different and slightly pendulous. The flowers are white to yellow, and generally only appear every two years, but in such abundance that the tree is completely covered on a single stalk. The pods are divided into several lobes, similar to the pods of small beans. Each lobe contains an oblong bean-shaped seed.

Figure I-1: Photo of sophora japonica.

Table I-1: Botanical classification of Sophora japonica.

Class	**Magnoliopsida**
Ordre	Fabales
Family	Fabaceae
subfamily	Fabiodeae
Tribe	Sophoreae
Genus	Styphnolobium
Species	Japonicum
Synonyms	Sophora japonica, Sophora korolkowi, Sophora pubescens, Sophora sinensis

II- RESULTS AND DISCUSSION

II-1: Gravimetric Analysis

II-1-1: Materials and Methods

Ordinary steel samples measuring 20 mm by 6 mm were used and cleaned by washing with distilled water, degreased with acetone, washed once more with distilled water, then dried, and weighed using an electronic balance (± 0.1 mg). The corrosive solution (NaCl 35 g/L) was prepared by diluting NaCl in distilled water. Concentrations of 100, 300, 500, 1000, and 1300 ppm of inhibitor were prepared in the electrolyte solution (NaCl 35g/L).

II-1-2 Preparation of Plant Extracts

The aerial part of Sophora was harvested in the month of June of the year 2022 in the city of Batna, dried in a dry and airy place sheltered from sunlight, then ground until obtaining a fine powder. The maceration of 400g of plant powder is carried out with 200 ml of methanol at room temperature for 3 days. After liquid-solid extraction and vacuum evaporation at a temperature of 50°C of the solvent (methanol), we obtained 160 g of the methanolic extract."

II-1-3 Weight Loss Tests

In the Weight loss experiment, steel samples with a surface area of 4.333 cm2 were completely suspended in a NaCl solution without and with methanol extract of Sophora at different concentrations at 298 K°. After 6 days, the samples were removed from the solution and cleaned with distilled water. Corrosion products were removed from the metal surface using filter paper. After rinsing with distilled water and drying, the samples were reweighed. The results obtained are shown in Table III-1.

From the Weight loss data obtained, the corrosion rate (V_corr) and inhibition efficiency, EI (%) and surface coverage ϴ were calculated according to the following equation [16.17]:

$$\mathrm{VCorr} = \frac{\Delta m}{At} \qquad (1)$$

$$\mathrm{EI}\ (\%) = \frac{\Delta m_{(blanc)} - \Delta m_{(inh)}}{\Delta m_{(blanc)}} * 100 = \left(1 - \frac{\Delta m_{(inh)}}{\Delta m_{(blank)}}\right) * 100x \qquad (2)$$

Table II- 1: Gravimetric corrosion parameters of steel in the absence and presence of inhibitors

inhibitor	*C (ppm)*	*Δm(mg)*	*V_{corr} (mg/cm²h)*	*θ*	*EI(%)*
Extract methanol	**Blanc**	3,7	0,0088		
	100	3,5	0,0084	0,0540	5,40%
	300	3,4	0,0081	0,0812	8,12%
	500	1,4	0,0033	0,6216	62,16%
	1000	0,9	0,0021	0,7558	75,58%
	1300	0,3	0,0007	0,9189	91,89%

Weight loss expressed as corrosion rate (V_corr) and inhibition efficiency (EI%) for steel samples in a 35 g/L NaCl solution containing different concentrations of Sophora methanol extract, as a function of inhibitor concentration at 298 K°. The (Figures III-1) show that inhibitor efficiency increases and corrosion rate decreases with increasing concentration of the inhibitors studied.

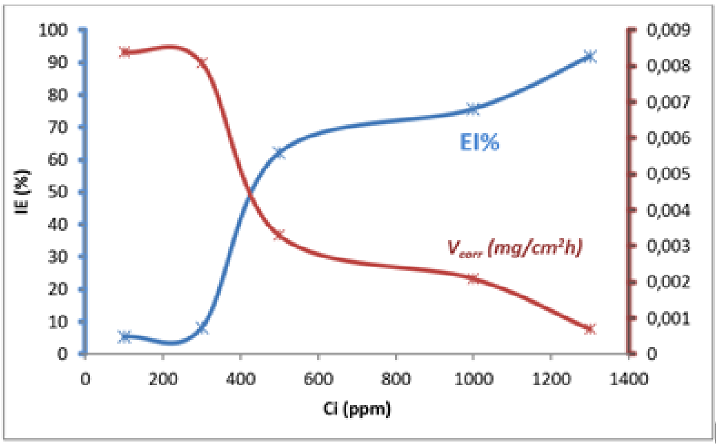

Figure II-1: Variation in corrosion rate and inhibition efficiency with different concentrations of methanol extract of sophora japonica at (298 K).

The histograms in Figure III.1 represent a comparison of the corrosion rate and inhibitor efficiency studied between inhibitor concentrations. Examination of these histograms shows that the maximum efficiency value is 91.89% and the minimum corrosion rate is 0.0007 mg/cm2h, indicating that methanolic extract of Sophora japonica is a good inhibitor for steel against corrosion in NaCl. According to the results obtained, we note that increasing the concentration of the inhibitor in the corrosive medium causes a decrease in the corrosion rate. This variation is probably linked to the strong interaction of the Sophora extract and its adsorption on the steel surface.

III-4: Adsorption Isotherms and Determination of Thermodynamic Parameters

Corrosion inhibition by organic molecules generally results from their adsorption to the metal surface. Determining the thermodynamic parameters characterizing the adsorption type often helps to elucidate the mode of action of these inhibitors. Depending on the nature of the interactions between the inhibitor molecules and the metal surface, two types of adsorption can be distinguished: chemisorption and physisorption. To model the adsorption process, several adsorption isotherms have been developed in the literature, such as Langmuir, Frumkin, Temkin, and Flory-Huggins [18, 19, 20, 21]. The various isotherms cited were tested, in order to find the most suitable adsorption isotherm. A Langmuir isotherm could be applied to this phenomenon, which is given by the following equation.

$$\frac{C_{inh}}{\theta} = \frac{1}{K_{ads}} + C_{inh} \qquad (3)$$

Where: Kads: is the equilibrium constant of the adsorption process. Cinh: inhibitor concentration in solution.

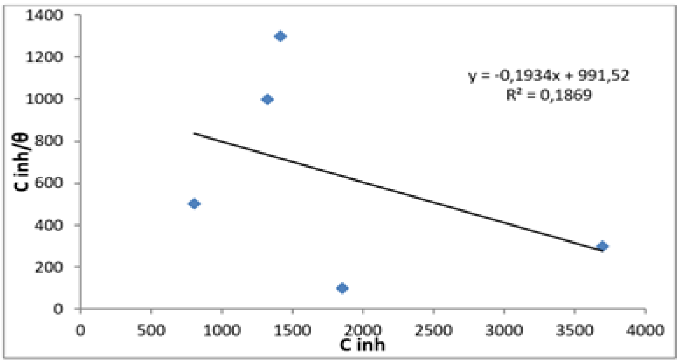

Figure II-2: Langmuir isotherm model for adsorption of methanoic extract of sophora on steel surface in NaCl 35g/L.

The characteristic model of the Frumkin adsorption isotherm is given by the following equation:

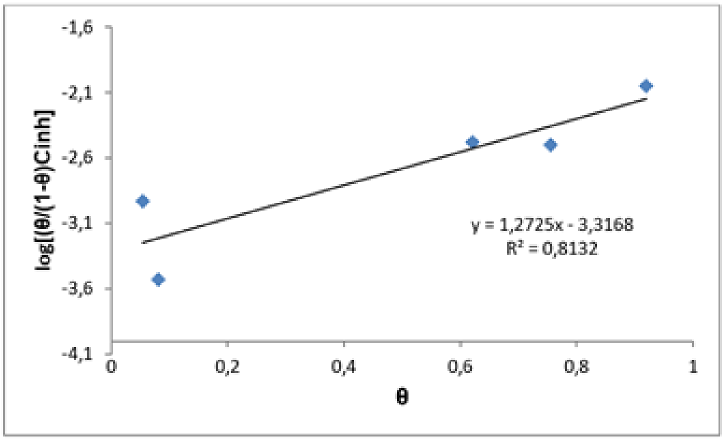

Figure II-3: Frumkin isotherm model for adsorption of methanoic extract of sophora on steel surface in NaCl 35 g/L.

The characteristic model of the Temkin adsorption isotherm is given by the following equation:

$$\exp(-2a\theta) = K_{ads}C \qquad (4)$$

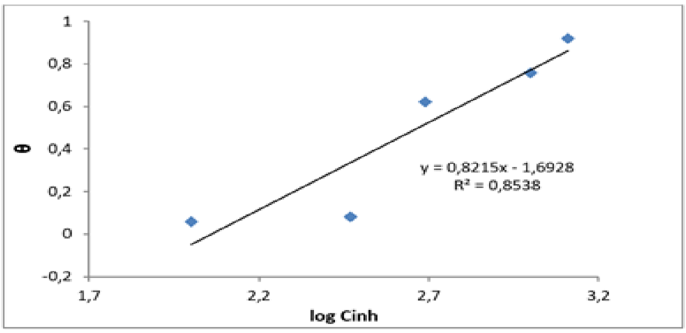

Figure II-4: Temkin isotherm model for adsorption of methanolic extract of sophora japonica on steel surface in NaCl 35 g/L.

The characteristic model of the Langmuir-Freundlich adsorption isotherm is given by the

$$\left(\frac{\theta}{1-\theta}\right)\exp(2a\theta) = K_{ads}C \qquad (5)$$

Following equation:

$$\Theta = K_{ads} \times \frac{Cinh}{1+(K_{ads} \times C_{inh})} \qquad (6)$$

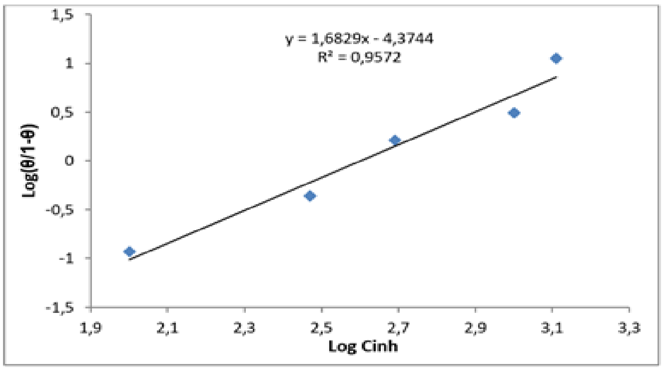

Figure II-5: Langmuir-Freundlich isotherm model for adsorption of methanoic extract of sophora on steel surface in NaCl 35g/L.

We note that the linear fit lines and their R2 correlation coefficients obtained for the isotherms tested show that the log (θ/1-θ) = f(log C_inh) representation is a straight line with correlation coefficients very close to 1 (R^2 = 0.9572), showing that our adsorption of methanolic extract on the steel surface obeys the Langmuir-Freundlich adsorption isotherm.

Table II-2: Linear regression parameters for each correlation coefficient (R2) case of sophora japonica methanolic extract

Isotherme	R^2	Slope	intercepte
Langmuir	0,1869	0,1934	+991,52
Temkin	0,8538	0,8215	-1,6928
Frumkin	0,8132	1,2725	-3,3168
Langmuir-freundlich	0,9572	1,6829	-4,3744

The standard free energy of adsorption (is related to the adsorption equilibrium constant (Kads) [52, 54] by the following equation:

$$\Delta G^{\circ}_{ads} = -RT\ ln\ (K_{ads} \times 55,55) \qquad (7)$$

Where: Kads is the adsorption equilibrium constant, Δ G°ads is the standard free energy of adsorption, 55.55 is the concentration of water in the solution in mol/l, R is the universal gas constant 8.31 j/mol K and T is the absolute temperature in Kelvin.
The values of K_{ads} and $\Delta G_{ads}°$ have been calculated and listed inTableVI-4.

Table II-3: Equilibrium constant (Kads) and free energy of adsorption (ΔG°ads) of sophora japonica methanol extract adsorbed to the steel surface in 35 g/l NaCl at 298 °K.

Temp. (°K)	R^2	K_{ads}(ppm^{-1})	ΔG_{ads} ° (KJ mole^{-1})
293	0,9874	0.0087	-13,75

The negative value of the standard free energy of adsorption -13.75 kJ mol^{-1} indicates the spontaneity of the adsorption process and the stability of the adsorbed layer on the copper surface. This suggests that the inhibitory action of the methanolic extract is due to electrostatic interactions between the secondary metabolites of the extract studied and the copper (physical adsorption) [22, 23, 24].

III: Potentiodynamic Polarization Measurements

Polarization curves are obtained in potentiodynamic mode, after the electrode has been immersed in the electrolyte for 3 hours, the time required to achieve equilibrium. Polarization curves in the absence and presence of the inhibitor methanolic extract of Sophora japonica, at concentrations of 500, 1000, and 1300 ppm in a corrosive medium NaCl 35 g/l. at 25°C are shown in figure II.6. The results show that the addition of Sophora japonica extract leads to a reduction in anodic and cathodic current densities. The Tafel curves (Figure II.6) can be used to determine the various electrochemical parameters of steel corrosion in this 35 g/l NaCl medium, in the absence and presence of the inhibitor. The inhibitor efficiency (EI') is calculated by applying the relationship (Eq. 8).

$$\mathbf{EI'\% = \left(1 - \frac{i'_{corr}}{i_{corr}}\right) \times 100} \qquad (8)$$

icorr and i'corr are the corrosion current densities of steel in the absence and presence of inhibitor respectively

$$\mathbf{\%IE = \theta \times 100 = \left(1 - \frac{icoor}{i°coor}\right) \times 100} \qquad (9)$$

Where i corr and i° corr are the corrosion current for the steel electrode without and with the inhibitor respectively. The values of corrosion current densities (icorr), corrosion potentials (Ecorr), cathodic and anodic slopes (βa and βc) and percentage inhibitor effectiveness (EI) are given in Table II.2.

Table II-4: Electrochemical corrosion parameters obtained

Conc. (ppm)	**E(mV)**	**i_{coor}(mA)**	**βc(mV)**	**βa(mV)**	**IE%**	**T_{cor}.mm/ans**
Blank	-696.7	2.8188	61.6	-196.9		0.033
500	-626.9	1.5971	55	-142.2	43.34	0.019
1000	-762.9	0.9142	72.7	-88.7	67.56	0.011

According to the results obtained: - The presence of Sophora extract causes a decrease in corrosion current (from 2.8188 mA to 0.5216 mA) and corrosion potential of steel (from -696.7 mV to -723.6 mV). - These results clearly show that both cathodic and anodic currents are affected by the addition of the inhibitor. Consequently, the action of this inhibitor, in the corrosive medium of NaCl 35 g/l, is of the mixed type. - The surface area of steel covered () in the presence of the methanolic extract is 0.9189 Electrochemical test results in agreement with gravimetric measurements.

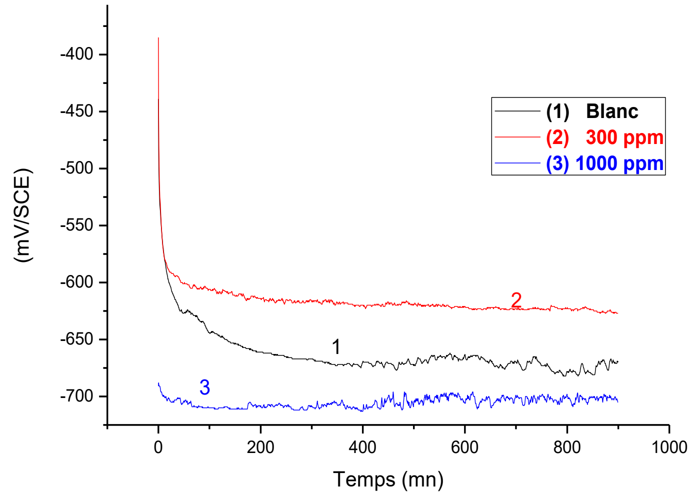

Figure III-1. OCP plots of steel in 35 g/l NaCl solution in the absence and presence of methanolic extract of sophora.

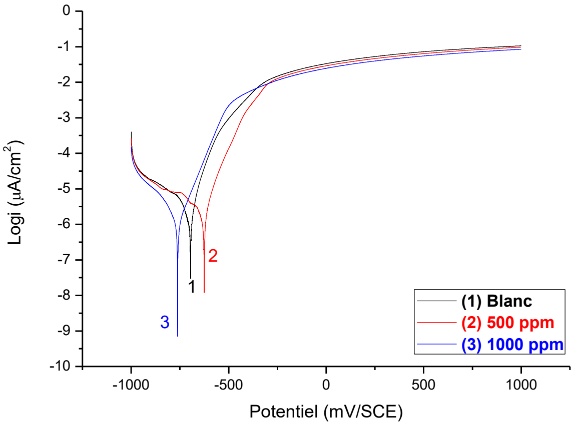

Figure III-2. Tafel representations of steel in 35 g/l NaCl solution in the absence and presence of methanolic extract of sophora.

Conclusion

Evaluation of anticorrosive activity using the gravimetric method (mass loss), where samples were immersed in a 35 g/l NaCl medium in the presence of different concentrations of methanolic extract of Sophora japonica (100ppm, 300ppm, 500ppm, 1000ppm, 1300ppm. The results show that increasing the concentration of the inhibitor in the corrosive medium leads to a decrease in corrosion rate. Meanwhile, inhibition efficiency increases, reaching a maximum value of 91.89% for a concentration of 1300 ppm. The thermodynamic data obtained indicate that our extract is physisorbed ($\Delta G°ads$ = -13.75 (KJ mole^{-1})) on the steel surface following the Langmuir-Freundlich isotherm. This study has enabled us to recognize the green inhibitor as an organic, non-toxic inhibitor; it is non-hazardous, available and inexpensive.

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