Entre Ciencia e Ingeniería, vol. 14, no. 27, enero-junio de 2020, páginas 99-106. DOI: https://doi.org/10.31908/19098367.1798.
ISSN 1909-8367 (Impreso), ISSN 2539-4169 (En línea)

Evaluation of the endocarp and epicarp extract of *Cereus fricii* cactus as a carbon steel corrosion inhibitor

Evaluación del extracto de endocarpio y epicarpio del cactus *Cereus fricii* como inhibidor de la corrosión de acero al carbono

A.G. Guzmán, P. Meza, C. Tejada, Á. Villabona-Ortiz, D. Acevedo

Recibido: diciembre 17 de 2019 – Aceptado: junio 25 de 2020

***Abstract*—Endocarp and pericarp extracts of *Cereus fricii* cactus were used to inhibit carbon steel corrosion in HCl and NaCl solutions by gravimetric assays. Extracts were mechanically obtained, concentrations were fixed and characterized by phytochemical testing and FTIR analysis, and the nature of inhibition was determined by calculation of Gibbs Free Energy. It was established that the extracts have the presence of tannins, saponins, and antioxidant compounds, which was corroborated by the FTIR analysis, showing peaks of absorbance corresponding to groups OH and COOH, with the endocarp extract presenting the highest proportion. Endocarp extracts with 5% concentration showed better performance in inhibiting corrosion than extracts obtained from epicarp, with percentages of 97.71 when inhibiting HCl and 73.91% with NaCl. The presence of tannins, saponins, and antioxidant compounds in extracts of the endocarp and epicarp favour inhibition of metal corrosion.**

***Keywords: Cereus fricii*, acid corrosion, alkaline corrosion, Langmuir isotherm**

***Resumen*—Se utilizaron extractos de Endocarpio y pericarpio de cactus *Cereus fricii* para inhibir la corrosión del acero al carbono en soluciones de HCl y NaCl mediante ensayos gravimétricos. Los extractos fueron obtenidos mecánicamente, las concentraciones fueron fijadas y caracterizadas por pruebas fitoquímicas y análisis FTIR y la naturaleza de la inhibición fue determinada por cálculo de Gibbs Free Energy. Se estableció que los extractos tienen la presencia de taninos, saponinas y compuestos antioxidantes, lo que fue corroborado por el análisis FTIR, mostrando picos de absorbancia correspondientes a los grupos OH y COOH, siendo el extracto de endocarpio el de mayor proporción. Los extractos de endocarpio con una concentración del 5% mostraron un mejor rendimiento en la inhibición de la corrosión que los extractos obtenidos del epicarpio, con porcentajes del 97,71 al inhibir el HCl y del 73,91% al inhibir el NaCl. La presencia de taninos, saponinas y compuestos antioxidantes en los extractos del endocarpio y del epicarpio favorecen la inhibición de la corrosión metálica.**

***Palabras clave: Cereus fricii*, corrosión ácida, corrosión alcalina, isoterma Langmuir.**

I. INTRODUCCIÓN

THE uses of chemical inhibitors is one of the most widely practiced methods for corrosion protection, especially in acidic environments, to prevent metal dissolution and acid consumption. Several organic and non-organic compounds have been studied as inhibitors to protect metals from corrosion. Organic compounds typically have a significant influence on the adsorption of the metallic surface and can, therefore, be used as effective corrosion inhibitors. The efficacy of these organic corrosion inhibitors is related to the presence of polar functions containing S, O, or N atoms that

[1] Product derived from the undergraduate thesis in chemical engineering "Inhibición de la corrosión del acero al carbono en medio ácido y salino empleando extractos de cactus (*Cereus fricii*)", Universidad de Cartagena.

A. G. Guzmán, Universidad de Cartagena, Cartagena de Indias, Colombia. Email: anamilen_17@hotmail.com
P. Meza, Universidad de Cartagena, Cartagena de Indias, Colombia. Email: pjmezac@gmail.com
C. Tejada, Universidad de Cartagena, Cartagena de Indias, Colombia. Email: ctejadat@unicartagena.edu.co
Á. Villabona-Ortiz, Universidad de Cartagena, Cartagena de Indias, Colombia. Email: avillabonao@unicartagena.edu.co.
D. Acevedo Universidad de Cartagena, Cartagena de Indias, Colombia. Email: dacevedoc@unicartagena.edu.co.

Como citar este artículo: Gúzman, A. G., Meza, P., Tejada, C., Villabona-Ortiz, A., Acevedo, D Evaluation of the endocarp and epicarp extract of Cereus fricii cactus as a carbon steel corrosion inhibitor, Entre Ciencia e Ingeniería, vol. 14, no. 27, pp.99-106, enero-junio 2020. DOI: https://doi.org/10.31908/19098367.1798.

are centers for the establishment of the adsorption process [1], [2].

In the aqueous medium, corrosion is of an electrochemical nature, which denotes the existence of an anodic zone (which suffers deterioration), a cathodic zone and an electrolyte, and the presence of these three elements is essential for the process to take place. Corrosion involves the movement of ions in the solution, which move from the active zones of the metal (anode) to less active zones (cathode), through the electrolyte, causing dilution and wear of the material. The metals that are attacked by an aggressive medium lose functionality, so it is necessary to implement actions for control and prevention.

The study of carbon steel corrosion inhibition using a green inhibitor in acidic and saline media, containing HCl or H_2SO_4 and NaCl, respectively, is currently one of the challenging research topics for various industries whose economic activities involve chemical cleaning, decalcification, pickling, acidifying acidification [3]. Metals such as iron, aluminum, copper, magnesium, and their alloys are used in a wide variety of structural, maritime, aeronautical, and cultural heritage applications, etc., which, although highly functional are susceptible to corrosion in aggressive environments [4].

Inhibitors have been used from natural products, such as *Punica granatum* extract [5], *Calligonum comosum* extract [6], *Vernonia amygdalina* [7], *Geissospermum laeve* [8], among others, which have been reported to be effective in reducing the rate of metal corrosion in corrosive media.

Roselli *et al.* [9] used extracts of yerba mate (*Ilex paraguariensis*) as a corrosion inhibitor of steel SAE 1010, obtaining the aqueous extract was obtained from the mixture of leaves and sticks of yerba mate of two commercial brands; they found that the extracts successfully inhibit corrosion in humid and saline environment, finding them suitable for addition as additives to anti-corrosion coatings.

The main objective of this project was to evaluate the efficiency of pericarp extract and epicarp from *Cereus fricii* cactus for inhibiting carbon steel corrosion in HCl and NaCl solutions through gravimetric tests. To determine the corrosion rate of carbon steel in the presence and absence of the extracts, comparing the performance of the epicarp extract with that of the endocarp extract with weight loss tests.

II. METODOLOGÍA

Experimental quantitative research was carried out to evaluate cactus extracts (*Cereus fricii*) as a corrosion inhibitor of carbon steel in acid and saline environments, based on the experimental design of factorial type 32, with a total of 16 experiments including replicates. The cactus stems that were used to obtain the endocarp and epicarp extracts or better known as carbon heart, came from the Montes de Maria region of the Department of Bolívar. Non-dry cactus were selected, and the extract was obtained to be used in inhibiting corrosion of carbon steel sheets of 3 x 4 cm x 0.3 mm. Conducting blank trials without inhibitors.

A. Obtaining and characterizing extracts

The extracts that were used were obtained from 500 g of cactus, where the pulp that was in the epicarp (center) and in the endocarp (external) of this one was subjected to a mechanical extraction by the expression, where it was later filtered, and the extracts were obtained. Concentrations of the inhibitor were set at 5 and 10% w v^{-1}, 3.5% w v^{-1} salt, and 0.5 M acid. Phytochemical tests were carried out on extracts obtained from both parts of the plant to identify the presence of secondary metabolites such as saponins and tannins, using abundant foam and gelatin-salt tests, respectively.

B. Corrosive media preparation and weight loss tests

The 0.5M HCl and NaCl 3.5% w v^{-1} solutions were prepared by diluting the acid and salt in distilled water. The NaCl solution was prepared at a concentration of 3.5% w v^{-1} based on the assumption that seawater consists of approximately 96.5% water and 3.5% dissolved salts, with an average of 35g of salt per liter of water. The main chemical elements found in the sea are chlorine, sodium, carbon, sulfur, calcium, potassium and magnesium in concentrations of 19 g L^{-1}, 11.0 g L^{-1}, 1.3 g L^{-1}, 1.0 g L^{-1}, 0.5 g $L^{-1,}$ and 0.4 g L^{-1}, respectively.

Weight loss tests were carried out by adding the two corrosive media in the presence of the cactus at the established concentrations, previously located in 16 containers (Sample and replica). In turn, 4 white containers were prepared (without adding extracts). Steel sheets were previously washed with 95% v v^{-1} ethanol to remove impurities, dried, and weighed in order to establish their weight before being exposed to corrosive media. The plates were immersed in the solution for 72 h, subsequently extracted, washed with ethanol, dried and weighed, thus determining weight loss, which established the mass of metal lost by corrosive effects. This process took place over six weeks every 72 h.

1) *Corrosion rate:* The corrosion rate is the amount of material per unit of time lost as a result of the reaction generated when in contact with a corrosive medium, and is calculated using Equation 1, taking into account the data obtained during weight loss tests.

$$V_c = \frac{m_f - m_i}{t} \qquad (1)$$

Where Vc is the corrosion velocity, m_f loss of metal mass after exposure to the corrosive medium, m_i initial metal mass before being exposed to the corrosive medium and t is the contact time at which it was exposed to the corrosive medium.

2) *Corrosion efficiency*: An inhibitor is efficient when it significantly decreases the rate of corrosion over metal or alloy. Once the corrosion velocity was obtained in each of the trials, the inhibition efficiency of cactus extracts was calculated at 72 h immersion using Equation 2.

$$EI\ (\%) = \frac{V_c - V_{ci}}{V_c} * 100 \qquad (2)$$

Where *Vc* is the rate of corrosion without inhibitor and *Vci* is the rate of corrosion with inhibitor.

3) *Degree of surface coverage*: FTIR analysis of the extracts was performed after the weight loss tests carried out, where Vc is the rate of corrosion without inhibitor, and Vci is the rate of corrosion with inhibitor. The composition of the extract will be analyzed following the specifications of Table 1

TABLE I
Concentrations of extracts to be analyzed using FTIR

Corrosive medium	**Parts of the cactus *Cereus fricci* (Cardon)**	
	Epicarp	**Endocarp**
Hydrochloric acid	10%	5%
Sodium chloride	10%	10%

The carbon steel coupons were initially washed with 95 % v v^{-1} ethanol and then immersed in the corrosive medium; after 7 days, the layers formed on the steel surfaces were extracted and removed with a spatula, dried to solidify, for further analysis by FTIR to determine the functional groups or metabolites present in the sample.

4) *Adsorption isotherms*: The interaction between metal and inhibitor extract was determined by adsorption isotherms. The assays were conducted at room temperature, preparing 7 containers with different concentrations of extract (1, 3, 5, 7, 10, 13 and 15 % v v^{-1}) and a target with the corrosive medium. Afterward, weight loss tests were carried out, obtaining the data that allowed to calculate the efficiency and degree of coating of the surface, making an adjustment of adsorption isotherm. Consequently, Gibbs' free energy and its parameters were estimated to establish the adsorption mechanism between metal and extract in the presence of the corrosive medium, based on Equations 3 and 4.

$$\frac{C}{\theta} = \frac{1}{K} + C \qquad (3)$$

Where C is the concentration of inhibitor extract (% v v^{-1}), θ is the degree of coating, and K is the constant adsorption.

$$\Delta G = -RT\ln(K * C_{ap}) \qquad (4)$$

Where R is the universal constant of gases, T is the ambient temperature, K is the adsorption constant and CAP is the concentration of pure water.

III. RESULTS AND DISCUSSIONS

A. *Characterization of the extracts*

Phytochemical tests were carried out on extracts obtained from both parts of the plant in order to identify the presence of saponins and tannins by means of abundant foam and gelatin-salt tests respectively, where the presence of these compounds was observed. For the abundant foam test, both extracts were taken, and hot water was added and then stirred. It showed an abundant and stable foam for endocarp extracts, indicating the presence of saponins. For the application of the gelatin-salt test, 25 g of gelatine without flavour was taken and soaked for one hour in a saturated solution of sodium chloride, then heated to achieve a complete dissolution, a portion of it was taken and added to the endocarp and epicarp extracts, forming a precipitate for both, which indicates the presence of tannins for both samples. The extracts were analyzed by tests of FTIR using dispersion in KBr, due to the content of water from endocarp pulp, with the objective of characterizing the functional groups and presence of metabolites, obtaining the following spectra. The IR spectrum for the extracts is shown in Fig. 1.

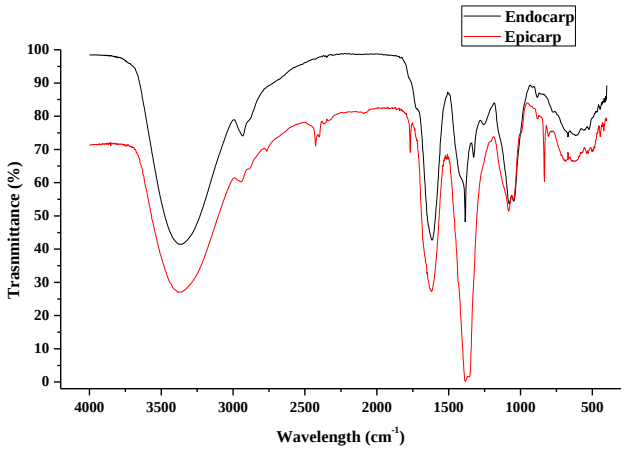

Fig. 1. IR spectrum of extracts

B. *Corrosion rate*

The study of weight loss allowed to evaluate the corrosion efficiency of the two extracts obtained from *Cereus fricci* cactus, the calculation of corrosion velocity was carried out using two concentrations of 5 % v v^{-1} and 10 % v v^{-1} for endocarp and epicarp extracts and in the corrosive media used (sodium chloride and hydrochloric acid). Fig. 2 shows the weight loss curves of carbon steel vs. immersion time of the plates in the presence and absence (Target) of the inhibitor extract obtained from the endocarp and pericarp of the cactus, as well as the corrosive media used and the two concentrations of the extracts.

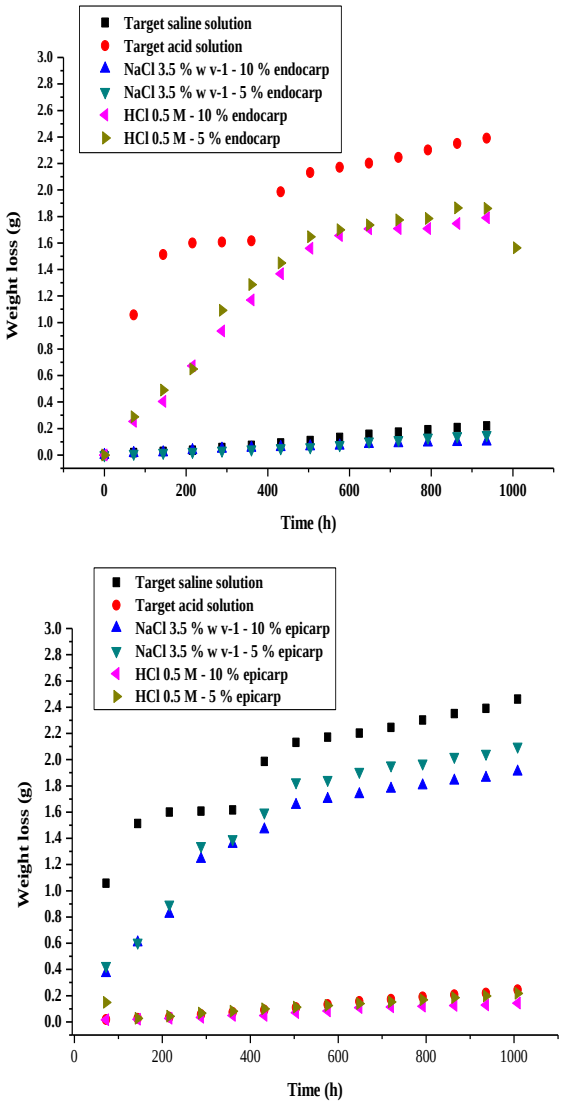

Fig. 2. Weight loss vs. time curves for carbon steel in NaCl and HCl in the presence and absence of endocarp extracts (up) and epicarp (down)

The graphs in Fig. 2 show that the weight slope vs. immersion time curves for carbon steel in the presence of the two extracts studied have a smaller slope than the whites' slopes; it is concluded that the extracts obtained from the cactus retard corrosion in the two corrosive media; indicating that the molecules of the extracts were adsorbed on the surface of the steel plates and subsequently extended their corrosion, working as an inhibitor. It is also shown that the extract that works as the best inhibitor to corrosion is the one obtained from endocarp in a 0.5 % v hydrochloric acid solution. Comparing the curves of corrosion velocity curves of the target samples in acidic medium with the curves from which the extract was added, it can be observed that those with the inhibitor have a lower weight loss, which indicates that it is more efficient.

On the slopes obtained from the target in the sodium chloride solution and in the presence of extracts, no significant variation of these curves could be observed. The two weight loss vs. immersion time graphs show that the weight loss of carbon steel plates increases with immersion time. The extracts with the highest efficiency, taking into account the type of extracts and corrosive medium exposed, were the epicarp extract at 10 % exposed to the sodium chloride solution with an efficiency of 55.61 %, the epicarp extract at 10 % exposed to the hydrochloric acid solution with an efficiency of 64.89 %, the endocarp extract at 10% exposed to sodium chloride solution with an efficiency of 73.91% and the endocarp extract at 5% exposed to a hydrochloric acid solution with an efficiency of 97.71%.

Using Equation 1, the values of the corrosion velocity of the submerged coupons in the different combinations of extract type, concentration, and corrosive medium were calculated, taking into account the following data shown in Table II.

TABLE II
Carbon steel corrosion rates in NaCl and HCl in the presence and absence of endocarp and epicarp extracts at different concentrations

Corrosive Medium	Concentration of the extract	Corrosion rate (g h^{-1})
NaCl 3.5 % p v^{-1}	Target	0.0002
HCl 0.5 M	Target	0.0024
NaCl 3.5 % p v^{-1}	10% Epicarp	0.0001
NaCl 3.5 % p v^{-1}	5% Epicarp	0.0002
HCl 0.5 M	10 % Epicarp	0.0019
HCl 0.5 M	5 % Epicarp	0.0021
NaCl 3.5 % p v^{-1}	10% Endocarp	0.0001
NaCl 3.5 % p v^{-1}	5% Endocarp	0.0002
HCl 0.5 M	10 % Endocarp	0.0018
HCl 0.5 M	5 % Endocarp	0.0018

C. Corrosion efficiency and degree of coating

Results of inhibition efficiency and aluminum coating results are shown in Table III. The extracts with the highest efficiency, taking into account the type of extracts and corrosive medium exposed, were the epicarp extract at 10 % exposed to the sodium chloride solution with an efficiency of 55.61 %, the epicarp extract at 10 % exposed to the hydrochloric acid solution with an efficiency of 64.89 %, the endocarp extract at 10% exposed to sodium chloride solution with an efficiency of 73.91% and the endocarp extract at 5% exposed to hydrochloric acid solution with an efficiency of 97.71%, all efficiencies were evaluated at room temperature.

Initially, a null hypothesis was established where the factors studied did not have a significant impact on inhibition efficiencies. Through the analysis of ANOVA variance carried out in the Statgraphics program shown in Table IV, the incidence of the concentration of the extract and the corrosive medium in corrosion inhibition was determined and which variable has the greatest incidence.

TABLE III
Inhibition efficiency and surface coating of carbon steel in the presence of NaCl and HCl with endocarp and pericarp extracts at different concentrations

Corrosive Medium	Extract concentration (%V)	Inhibition efficiency (%)	Coating Θ
Sodium Chloride	10 % Epicarp	55.61	0.5561
Sodium Chloride	5 % Epicarp	43.77	0.4377
Hydrochloric acid	10 % Epicarp	64.89	0.6489
Hydrochloric acid	5 % Epicarp	60.62	0.6062
Sodium Chloride	10 % Endocarp	73. 91	0.7391
Sodium Chloride	5 % Endocarp	55.55	0.5555
Hydrochloric acid	10 % Endocarp	95.86	0.9586
Hydrochloric acid	5 % Endocarp	97. 71	0.9771

TABLE IV
Analysis of variance for inhibition efficiency

	p-value
A: Corrosive Medium	0.0000
B: Extract	0.0000
C: Extract concentration	0.0011
AB	0.0014
AC	0.0181
BC	0.6866

The ANOVA table partitions the Efficiency variability into separate pieces for each of the effects. Then test the statistical significance of each effect by comparing its mean square against an experimental error estimate. In this case, five effects have a P-value lower than 0.05, indicating that they are significantly different from zero with a confidence level of 95.0%. In addition, a statistical R^2 of 98.2139% was obtained. The Pareto diagram (Fig. 3) shows that the concentration of the extract is the variable with a positive incidence on the process, while the corrosive medium and the type of extract have a negative impact.

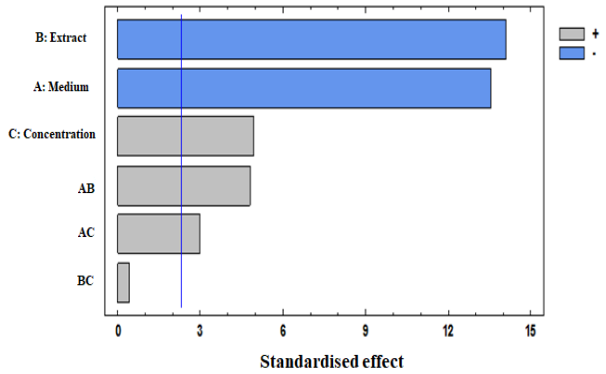

Fig. 3. Pareto diagram for inhibition efficiency.

D. *Characterization of the film formed on coupons*

Four conditions of extract concentration, extract type and corrosive medium were selected from the tests previously performed. Table V shows the combinations of concentrations used in each corrosive medium analysed.

TABLE V
Concentrations used in each corrosive medium analysed

Corrosive Medium	Parts of the cactus *Cereus fricci* (Cardón)	
	Epicarp	Endocarp
Hydrochloric acid	10 % v v^{-1}	5 % v v^{-1}
Sodium Chloride	10 % v v^{-1}	10 % v v^{-1}

Fig. 4 shows the FTIR analysis of the film formed on the surface of the coupons in contact with the corrosive medium in the presence of the extracts, where Sample 1 corresponds to the coupon in NaCl and epicarp extract with 10% concentration, Sample 2 corresponds to the coupon in NaCl and endocarp extract with 10% concentration, Sample 3 to coupon in HCl and epicarp extract with 10% concentration, and finally Sample 4 to coupon in HCl and endocarp extract with 5% concentration.

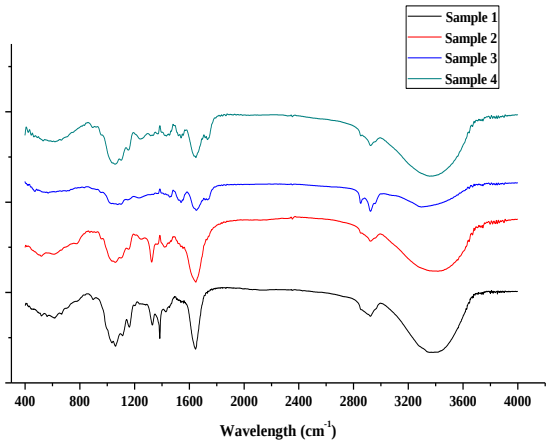

Fig. 4. IR spectrum of the layer formed on carbon steel coupons exposed to corrosive media in the presence of endocarp and pericarp extracts.

Equation 1 was used to calculate the corrosion velocity, Equation 2 was used to calculate the inhibitor efficiency and Equation 2 to obtain the coating degree values, the data obtained are shown in the following graph and were used to adjust the Langmuir isothermal equation. The data is summarized in Table VI.

The data obtained from the adsorption isothermal test at 25°C for carbon steel in HCl in the presence of endocarp extract showed an adjustment to the Langmuir isotherm, allowing to know the interaction between the inhibitor extract and the metal (carbon steel), i.e., how the inhibitor is adsorbed on the steel surface, by calculating Gibbs's free energy [10].

When graphing the relationship between inhibitor concentration and surface area covered vs. inhibitor concentration, Fig. 4 was obtained, which showed an adjustment quite close to a straight line (R^2 = 0.997), which correlated with the behavior of the Langmuir isotherm.

TABLE VI

Corrosion rate, inhibition efficiency (% IE) and degree of coating (coating Θ) of carbon steel in HCl 1M in the presence of endocarp extract during 72 h exposure.

Extract concentration (%V)	Corrosion rate (g h^{-1})	% IE	Coating θ
1%	0.0235	59.1059	0.5911
3%	0.0066	73.9514	0.7395
5%	0.0072	60.2097	0.6021
7%	0.0058	76.8764	0.7688
10%	0.0002	73.6203	0.7362
13%	0.0075	70.2539	0.7025
15%	0.0075	70.3091	0.7025
Target	0.0252	-	

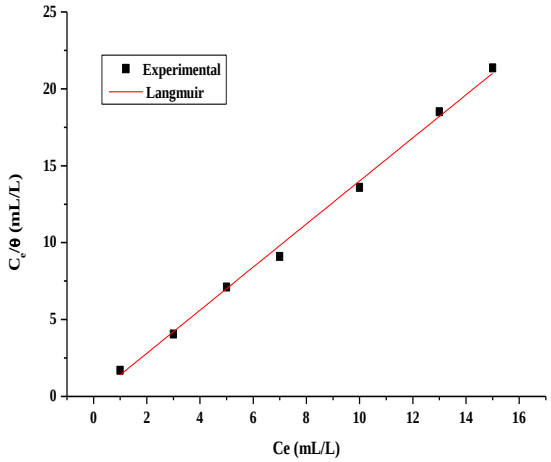

Fig. 5. Langmuir adsorption isotherm.

Taking into account Equation 4 and that the adjustment of the isotherm in Fig. 4 is a straight line of Equation 5:

$$y = 1{,}3931x - 0{,}1957 \qquad (5)$$

Then the adsorption constant is:

$$\frac{1}{k} = 0{,}1957 \rightarrow k = \frac{1}{0{,}1957} = 5{,}109862$$

Replacing the parameters in equation 5 calculated Gibbs' free energy.

$$\Delta G = -21{,}36878607\ kJ\ mol^{-1}$$

The value obtained for Gibbs free energy of -22,36561 kJ mol^{-1} corresponds to the physical adsorption or physorption mechanism indicating the interaction between adsorbent and adsorbent, thus indicating a weak interaction.

The calculation of Gibbs's free energy was done using other equations to obtain the parameters required to adjust the isotherm of Langmuir and to obtain the numbered value of the adsorption constant k. From Equations 1, 2 and 3 the corrosion velocity, degree of coating, and inhibition efficiency were calculated. The data obtained by these equations are shown in Table VII, with which the Langmuir isotherm was adjusted.

TABLE VII
Concentration of endocarp extract, corrosion rate, efficiency and degree of coating.

Extract concentration	Corrosion rate g/hm^2	% IE	Coating θ
1%	40.014	59.1059	0.5911
3%	25.488	73.95144	0.7395
5%	38.934	60.2097	0.6021
7%	22.626	76.87638	0.768763797
10%	25.812	73.6203	0.736203091
13%	29.106	70.2538	0.70254
15%	29.106	70.3091	0.70254
Target	97.848	-	

The parameters calculated by these equations comparing them with the previous ones are the same, so the adjustment graph will be the same, obtaining the same value of the adsorption constant and the Gibbs's free energy.

Tannins are organic compounds with molecular formula $C_{14}H_{14}O_{11}$, which thanks to their oxygen atoms are adsorbed on the surface of the metal forming complexes that act as a protective layer, decreasing the contact area between the metal and the corrosive medium and therefore the rate of corrosion. The presence of OH groups in tannins confers the capacity to form chelates and salts with iron ions and other metallic cations [11], [12]. OH groups around the molecule are attracted to form strong bonds with hydrogen and thus form complexes with metal ions. The complexes thus formed cause a blockage in the microanode formation sites, which are generated when the metallic surface comes into contact with an electrolyte or corrosive medium, thus delaying the dissolution of the metal [11], [13].

The results obtained from the FTIR analysis in Fig. 1 of the two extracts show the presence of organic compounds such as tannins $C_{14}H_{14}O_{11}$ and phenols $C_6H_6O_6$. Previous studies have obtained that the FTIR spectra of tannins are shown in a wide absorption range with a maximum absorbance band at 3413 cm^{-1} due to the presence of hydroxyl groups [11], the peaks between 1600 and 1450 cm^{-1} are characteristic of aromatic compounds, and those between 600-1300 cm^{-1} correspond to benzene substitution rings [14].

The presence of functional groups such as OH-, NH and the presence of antioxidants such as phenols were found in the two extracts analysed. In previous studies have analyzed the interaction of these groups with the metal surface, the OH-functional group can protect steel coupons against corrosion by the interaction of the corrosive medium and metal, reacting with Fe^{3+} ions to form chelates with iron responsible for the corrosion inhibitory capacity of carbon steel exposed to different corrosive media, this is due to the ortho-position of the OH- group in aromatic rings [11]. In the case of amines, they have been found to generate a layer on the metal to protect it from the exposed corrosive environment and thus protect it [15].

The results obtained demonstrate the potential use of cactus extracts as corrosion inhibitors in comparison to other extracts given their tannin and phenol content, which allow high corrosion inhibition efficiencies to be obtained. Several authors have worked with corrosion inhibitors from plant extracts, obtaining similar results to those found in the present research so that we can make a comparison with these studies. Table VIII shows the inhibition efficiencies obtained by other research using other plants such as carbon steel and aluminum inhibitors in acid and basic media.

TABLE VIII
Comparison of the research carried out with other plants in carbon steel

Plant	Metal	Corrosive medium.	Efficiency (%)	Author
Geissospermum laeve	Carbon Steel C 38	HCl 1M	92 %	Faustin *et al.*, [8]
Tagetes erecta	Mild steel	H_2SO_4 0.5 M	91.6 %	Mourya *et al.*,. [16]
Eruca sativa	Carbon Steel	H_2SO_4 0.1 M	92 %	Sobhi *et al.*,. [17]
Sida acuta	Mild steel	H_2SO_4 1 M	85 %	Umoren *et al.*,. [12]
Mansoa alliacea	Zinc	NaCl 3%	90 %	Saudile *et al.*,. [18]
Santolina chamaecyparissus	Stainless steel	NaCl 3.5 M	90.08 %	Loto *et al.*, [7]

In some studies, the trend is for corrosion inhibition efficiency to be proportional to the concentration of the extracts used [19], but when the corrosion inhibitor is composed of many secondary metabolites such as tannins, saponins, and phenols (with high content of functional groups O-H) and used in a saline solution, a higher concentration would imply forming a thicker layer between the metal and the corrosive medium, which leads to an excess of hydroxyl groups adhering to the metal that would react with the sodium chloride solution in this case to generate acid salts which when adhered to the metal degrade it.

In the spectrum obtained from the layer formed in the carbon steel coupon exposed to the corrosive medium of hydrochloric acid in the presence of the epicarp extract at 10% shown in Fig. 4, secondary metabolites of interest in the O-H group are present in 3 406.29 cm^{-1} and carboxylic acids in the wavelengths of 1 647.21 and 2 852.72 cm^{-1}.

Elbeshary and Mohammed [20] obtained that these groups possess good corrosion inhibitory capacity, and that this depends on the length of the carbon chain and its concentrations. The absorption spectra of the protective layers formed between the steel plate and the solutions of hydrochloric acid and sodium chloride respectively in the presence of endocarp extracts at 10 % and 5 %. And in these, almost the same absorption curve is presented obtained for the analysis of the extract alone, which indicates that the chemical structures of the components of interest in this case, saponins, tannins and flavonoids that are present in the 3500-3200 m^{-1} wide side do not decompose in the exposed corrosive medium [21].

Where the physsorption is an electrostatic attraction between the inhibitor and the metal, which slows down the anodic and cathodic reactions that lead to metal corrosion, and the chemisorption depends on the reactivity between adsorbent and adsorbate, it depolarizes the corrosive agents and water molecules adsorbed on the metal. Previous studies of different extracts determined the corresponding values of Gibbs free energy corresponding to each type of adsorption, negative values up to -20 kJ mol^{-1} correspond to the physical adsorption mechanism and values of -40 kJ mol^{-1} or more negative values indicate chemical adsorption [22].

Researchers, in determining the mechanism of metal-extract adsorption, have found that most of the interactions that occur are by physorption; Firstly, *Euphorbia falcata* extract was evaluated in carbon steel plates in acidic medium obtaining high efficiencies in corrosion inhibition by increasing the extract concentration, experimental data were adjusted to Langmuir adsorption isotherm and when calculating Gibbs free energy a value of -23.92 kJ mol^{-1} was obtained which indicated a physical adsorption [23].

Similarly, Li *et al.* [24] reached similar values of -20.1 kJ mol^{-1} and -19.9 kJ mol^{-1} for 45 and 25 °C respectively, when studying by potentio-dynamic polarization, electrochemical impedance spectroscopy, atomic force microscopy, Fourier transform infrared spectroscopy and quantum chemistry calculations the corrosion inhibiting capacity of the leaves of the *Osmanthus fragans* tree on carbon steel in hydrochloric acid 1M.

IV. CONCLUSION

Through phytochemical tests carried out on the extracts of the endocarp and epicarp of *Cereus fricci*, tannins, saponins and antioxidant compounds that favour the inhibition of metal corrosion were found to be present, due to the fact that when adsorbed on the surface of carbon steel they generate a protective layer, which when characterized evidenced the presence of these organic compounds in the film formed between a metal and corrosive medium without degrading them. FTIR analyses showed the presence of OH and COOH groups, confirming the presence of tannins and saponins in greater proportion in the endocarp extract, and the non-degradation of the sample when subjected to corrosive media. The endocarp extracts, in turn, presented a better performance in inhibition of corrosion than the extracts obtained from the epicarp of the cactus, being of the evaluated concentrations of 5%, the one that presented a greater efficiency with 97.71%. The behavior of the corrosive inhibition with epicarp extracts is directly proportional to the concentration. The negative values up to -20 kJ mol^{-1} obtained in Gibbs' Free Energy state that the mechanism of adsorption of the endocarp extract on the metal plate in the presence of corrosive agents corresponds to physisorption and that the process is spontaneous. From the results obtained, it is established that the endocarp extract of *C. fricci* cactus can be used to inhibit the corrosion of carbon steel plates in saline and acidic media.

ACKNOWLEDGEMENT

The authors thank the Universidad de Cartagena for the support to develop this research, laboratories, software, and time of the research professors.

.

References

[1] G. I. Ostapenko, P. A. Gloukhov, and A. S. Bunev, "Investigation of 2-cyclohexenylcyclohexanone as steel corrosion inhibitor and surfactant in hydrochloric acid," *Corros. Sci.*, vol. 82, pp. 265–270, May 2014.

[2] R. Yıldız, A. Döner, T. Doğan, and İ. Dehri, "Experimental studies of 2-pyridinecarbonitrile as corrosion inhibitor for mild steel in hydrochloric acid solution," *Corros. Sci.*, vol. 82, pp. 125–132, May 2014.

[3] H. Bentrah, Y. Rahali, and A. Chala, "Gum Arabic as an eco-friendly inhibitor for API 5L X42 pipeline steel in HCl medium," *Corros. Sci.*, vol. 82, pp. 426–431, May 2014.

[4] N. D. Nam *et al.*, "The behaviour of praseodymium 4-hydroxycinnamate as an inhibitor for carbon dioxide corrosion and oxygen corrosion of steel in NaCl solutions," *Corros. Sci.*, vol. 80, pp. 128–138, Mar. 2014.

[5] M. Behpour, S. M. Ghoreishi, M. Khayatkashani, and N. Soltani, "Green approach to corrosion inhibition of mild steel in two acidic solutions by the extract of Punica granatum peel and main constituents," *Mater. Chem. Phys.*, vol. 131, no. 3, pp. 621–633, Jan. 2012.

[6] M. Shabani-Nooshabadi, F. S. Hoseiny, and Y. Jafari, "Green Approach to Corrosion Inhibition of Copper by the Extract of Calligonum comosum in Strong Acidic Medium," *Metall. Mater. Trans. A*, vol. 46, no. 1, pp. 293–299, Jan. 2015.

[7] C. A. Loto, O. O. Joseph, and R. T. Loto, "Inhibition effect of Vernonia amygdalina extract on the corrosion of mild steel reinforcement in concrete in 0.2 M H 2 SO 4 Environment," *Eur. J. Environ. Civ. Eng.*, vol. 17, no. 10, pp. 1026–1038, Nov. 2013.

[8] M. Faustin, A. Maciuk, P. Salvin, C. Roos, and M. Lebrini, "Corrosion inhibition of C38 steel by alkaloids extract of Geissospermum laeve in 1M hydrochloric acid: Electrochemical and phytochemical studies," *Corros. Sci.*, vol. 92, pp. 287–300, Mar. 2015.

[9] S. Roselli, S. Bogdan, C. Deyá, and R. Romagnoli, "Inhibidor anticorrosivo eco-amigable para recubrimientos acuosas protectoras del acero: Ylex paraguariensis (yerba mate)," *Av. en Cienc. e Ing.*, vol. 7, no. 3, pp. 65–72, 2016.

[10] R. Touir, M. Cenoui, M. El Bakri, and M. Ebn Touhami, "Sodium gluconate as corrosion and scale inhibitor of ordinary steel in simulated cooling water," *Corros. Sci.*, vol. 50, no. 6, pp. 1530–1537, Jun. 2008.

[11] R. S. Peres, E. Cassel, and D. S. Azambuja, "Black Wattle Tannin As Steel Corrosion Inhibitor," *ISRN Corros.*, vol. 2012, pp. 1–9, 2012.

[12] S. A. Umoren, U. M. Eduok, M. M. Solomon, and A. P. Udoh, "Corrosion inhibition by leaves and stem extracts of Sida acuta for mild steel in 1M H2SO4 solutions investigated by chemical and spectroscopic techniques," *Arab. J. Chem.*, vol. 9, pp. S209–S224, Sep. 2016.

[13] B. E. A. Rani and B. B. J. Basu, "Green Inhibitors for Corrosion Protection of Metals and Alloys: An Overview," *Int. J. Corros.*, vol. 2012, pp. 1–15, 2012.

[14] L. Tejeda Benítez, C. Tejada Tovar, W. Marimón Bolívar, and Á. Villabona Ortiz, "Estudio de modificación química y física de biomasa (Citrus sinensis y Musa paradisiaca) para la adsorción de metales pesados en solución.," *Rev. Luna Azul*, vol. 39, no. 1, pp. 124–142, 2014.

[15] M. J. Garcia-Ramirez, G. F. Dominguez Patiño, J. G. Gonzalez-Rodriguez, M. L. Dominguez-Patiño, and J. A. Dominguez-Patiño, "A Study of Eruca vesicaria, Bromelia hemisphaerica and Erythrina americana as Green Corrosion Inhibitors for Carbon Steel in Sulfuric Acid," *Adv. Mater. Phys. Chem.*, vol. 6, no. 2, pp. 9–20, 2016.

[16] P. Mourya, S. Banerjee, and M. M. Singh, "Corrosion inhibition of mild steel in acidic solution by Tagetes erecta (Marigold flower) extract as a green inhibitor," *Corros. Sci.*, vol. 85, pp. 352–363, Aug. 2014.

[17] M. Sobhi, H. H. El-Noamany, and A. Y. El-Etre, "Inhibition of Carbon Steel corrosion in Acid mediumin by Eruca sativa Extract," *J. Basic Environ. Sci.*, vol. 2, no. July, pp. 9–18, 2015.

[18] F. Suedile, F. Robert, C. Roos, and M. Lebrini, "Corrosion inhibition of zinc by Mansoa alliacea plant extract in sodium chloride media: Extraction, Characterization and Electrochemical Studies," *Electrochim. Acta*, vol. 133, pp. 631–638, Jul. 2014.

[19] M. Finšgar and J. Jackson, "Application of corrosion inhibitors for steels in acidic media for the oil and gas industry: A review," *Corros. Sci.*, vol. 86, pp. 17–41, Sep. 2014.

[20] E. A. A. Mohammed, M. De Keersmaecker, and A. Adriaens, "Inhibition of the corrosion of iron heritage objects after treatment with long-chain monocarboxylic acids in ethanolic solutions," *Prog. Org. Coatings*, vol. 101, pp. 225–232, Dec. 2016.

[21] X. Li, S. Deng, and H. Fu, "Inhibition of the corrosion of steel in HCl, H2SO4 solutions by bamboo leaf extract," *Corros. Sci.*, vol. 62, pp. 163–175, Sep. 2012.

[22] G. Quartarone, L. Ronchin, A. Vavasori, C. Tortato, and L. Bonaldo, "Inhibitive action of gramine towards corrosion of mild steel in deaerated 1.0M hydrochloric acid solutions," *Corros. Sci.*, vol. 64, pp. 82–89, Nov. 2012.

[23] A. El Bribri, M. Tabyaoui, B. Tabyaoui, H. El Attari, and F. Bentiss, "The use of Euphorbia falcata extract as eco-friendly corrosion inhibitor of carbon steel in hydrochloric acid solution," *Mater. Chem. Phys.*, vol. 141, no. 1, pp. 240–247, Aug. 2013.

[24] L. Li, X. Zhang, J. Lei, J. He, S. Zhang, and F. Pan, "Adsorption and corrosion inhibition of Osmanthus fragran leaves extract on carbon steel," *Corros. Sci.*, vol. 63, pp. 82–90, Oct. 2012.

Ana García Guzmán. Ingeniera Química de la Universidad de Cartagena. Miembro del grupo de investigación IDAB.

Pedro Meza Castellar. Ingeniero Químico y Especialista en Ingeniería Ambiental de la Universidad Nacional de Colombia sede Bogotá, M.Sc. en Ingeniería Ambiental de la Universidad de Cartagena y Ph. D(c) en Agrociencias de la Universidad de la Salle. Miembro del grupo de investigación IDAB.

Candelaria Tejada Tovar. Ingeniera Químico, M.Sc. en Ingeniería Ambiental de la Universidad de Cartagena, Cartagena de Indias, Colombia, entre 2010 y 2012. Desde 1995 hasta la fecha, ha trabajado con la Universidad de Cartagena. Miembro del grupo de investigación IDAB.
ORCID: https://orcid.org/0000-0002-2323-1544.

Ángel Villabona Ortiz Ingeniero Químico, M.Sc. en Ingeniería Ambiental en la Universidad de Cartagena, Cartagena de Indias, Colombia, entre 2010 y 2014. Desde 1997 hasta la fecha, ha trabajado con la Universidad de Cartagena. Miembro del grupo de investigación IDAB.
ORCID: https://orcid.org/0000-0001-8488-1076.

Diofanor Acevedo Correa. Químico Farmacéutico e Ingeniero de Alimentos de la Universidad de Cartagena, Especialista en Ciencia y Tecnología de Alimentos de la Universidad Nacional (Colombia) y Doctor en Ingeniería de Alimentos de la Universidad del Valle (Colombia). Es investigador del Grupo de Investigación IDAA de la Universidad de Cartagena y docente de planta de la misma universidad. ORCID: https://orcid.org /0000-0002-1364-7044