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Article

Evaluation of Guava Seeds as a Natural Inhibitor in Corrosive Medium on AISI/SAE 1020 Steel

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RESUMO

A corrosão é um desafio natural e inevitável que provoca a deterioração de inúmeros materiais. O aço carbono é um material amplamente utilizado na indústria que requer excelentes propriedades mecânicas, bem como elevada resistência à corrosão. O objetivo deste trabalho foi estudar a ação inibidora de sementes de goiaba na corrosão do aço carbono AISI/SAE 1020. Para analisar a taxa de corrosão e avaliar a eficiência do inibidor, foram realizados ensaios de perda de massa em amostras retangulares de aço AISI 1020 com e sem a presença do inibidor para tecer comparações. Para tal, as amostras ficaram expostas durante 21 dias nos seguintes meios corrosivos: H_2O, solução de cloreto de sódio (NaCl) 1 mol L^{-1} e ácido clorídrico (HCl) 1 mol L^{-1}. Os resultados mostraram que o inibidor utilizado foi efetivo, pois promoveu diminuição da perda de massa, bem como redução da taxa de corrosão em relação às amostras ensaiadas sem a presença dele. Em relação à eficiência de inibição, o inibidor de corrosão foi mais efetivo em meio ácido, com eficiência de 59,11% comparado com o meio neutro, tomando como parâmetros os resultados obtidos nos ensaios gravimétricos.
Palavras-chave: corrosão, taxa de corrosão, eficiência de inibição, aço carbono 1020, perda de massa.

ABSTRACT

Corrosion is a natural and inevitable challenge that causes many materials to deteriorate. Industry widely uses carbon steel, a material that demands excellent mechanical properties and high corrosion resistance. This study investigated the inhibitory action of guava seeds on the corrosion of AISI/SAE 1020 carbon steel. In order to analyze the corrosion rate and evaluate the efficiency of the inhibitor, mass loss tests were carried out on rectangular samples of AISI 1020 steel with and without the inhibitor to make comparisons. To do so, the samples were exposed for 21 days to the following corrosive environments: $H_{(2)}O$, sodium chloride solution (NaCl) 1 mol L^{-1}, and hydrochloric acid (HCl) 1 mol L^{-1}. The results showed that the inhibitor used was effective, as it led to a reduction in mass loss, as well as a reduction in the corrosion rate compared to the samples tested without it. As regards inhibition

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efficiency, the corrosion inhibitor was more effective in acidic environment, with an efficiency of 59.11% compared to neutral environment, considering the results obtained in the gravimetric tests as parameters.

Keywords: corrosion, corrosion rate, inhibition efficiency, 1020 carbon steel, mass loss.

Introduction

To a greater or lesser extent, most materials have some kind of interaction with a large number of different environments. Such interactions often compromise the usefulness of a material as a result of deterioration in its mechanical properties (e.g. ductility and strength), other physical properties or its appearance (Callister & Rethwisch, 2019).

Due to the damage caused by corrosion in a wide variety of activities, the search for protection methods has become ever greater. There are various methods for combating corrosion threats, such as cathodic protection, anodic protection, coating, material selection, the use of corrosion inhibitors, among others. Among the different ways of controlling corrosive processes in metals in order to increase the useful life of metallic materials, the use of inhibitors is one the most common methods, as they are efficient and easy to implement. Inhibitors are organic or inorganic chemical compounds that are usually inserted in small quantities into the corrosive environment in order to protect metallic materials from dissolution and aggression processes. These substances, if added in suitable concentrations, can slow down or inhibit corrosion, thereby reducing the economic losses caused by these corrosive processes (Gentil, 2022; Chauhan, et al., 2022).

Unfortunately, many of the compounds used as corrosion inhibitors are non-biodegradable synthetic chemicals which, although they guarantee high inhibition efficiency, can be very expensive and dangerous for living beings and the environment due to their high level of toxicity. These effects, together with the concern to generate processes that are not aggressive to the ecosystem, have increased the search for economically and ecologically viable products (Quadros et al., 2020).

In view of this, there is growing interest in the use of plant extracts and biodegradable materials as natural corrosion inhibitors, as these products are inexhaustible and easily accessible, as well as being inexpensive to obtain, biodegradable and especially non-toxic. Research carried out in recent years has shown that many plants contain compounds with antioxidant action, mainly polyphenols, which guarantee an inhibitory effect, proving the efficiency of these natural products (Rocha & Gomes, 2017; Silva et al., 2025).

The aim of this work is to study the inhibitory effect of guava seed powder on the corrosion of AISI/SAE 1020 carbon steel immersed in a medium of H_2O, NaCl and HCl 1 mol L^{-1}, a at room temperature.

Bibliographic review

By definition, steel is an iron-carbon alloy generally containing 0.008% to approximately 2.11% carbon, plus certain residual elements resulting from manufacturing processes (Chiaverini, 2012). According to Pfeil & Pfeil (2021), steel is an alloy of iron and carbon, with other elements of two types: residual elements resulting from the manufacturing process, such as silicon, manganese, phosphorus and sulphur, and elements added in order to improve the physical and mechanical characteristics of the material, called alloying elements. Depending on the presence in the chemical composition of alloying elements and the content of residual elements, steels are classified as carbon steels and alloy steels.

The Society of Automotive Engineers (SAE), the American Iron and Steel Institute (AISI) and the American Society for Testing and Materials (ASTM) are responsible for the classification and specification of steels as well as other alloys. The AISI/SAE specification for these steels consists of a four-digit number, the first two digits indicate the type of alloy and the last two digits give the carbon concentration (Callister & Rethwisch, 2019).

In Brazil, steels are described according to their chemical composition according to the Brazilian Association of Technical Standards (ABNT, 2000), in line with the criteria adopted by AISI and SAE. Thus, the first two digits designate the steel grade, and the last two designate the average carbon content, in percentage.

Carbon steels are designated by four digits. The first two indicate that it is carbon steel, designated by the number 10, and the last two indicate the amount of carbon, in porcentage. Thus, a 1020 steel is a carbon steel with 0.2%C, and the standard allows a variation of 0.05%C as a tolerance, i.e. for 1020 steel between 0.18% and 0.23%C. AISI/SAE 1020 steel is widely used in applications requiring good machining properties and weldability. However, the same composition that gives the steel its malleability and ease of processing also makes it vulnerable to corrosion. Without the presence of alloying elements such as chromium or nickel, which provide additional resistance to corrosion, 1020 steel tends to corrode more quickly when exposed to aggressive environments such as humid atmospheres or saline solutions (Chiaverini, 2012; Kumar & Singh, 2024).

The definition of corrosion is expressed in different ways by different authors. According to Gentil (2022), in a very widespread and universally accepted aspect, corrosion can be defined as the deterioration of a material, usually metallic, by chemical or electrochemical action of the environment, associated or not with mechanical stress. According to Felipe et al. (2013), corrosion is a natural process that can be easily found on different types of surfaces, and represents one of the main causes of economic losses in the industrial sector.

Corrosion is sometimes identified as the inverse process of extractive metallurgy. While extractive metallurgy deals with the transformation of ore into alloys ready for use in engineering, corrosion causes the destruction of metals and metal alloys by transforming them into oxides or hydroxides (Kobzar & Fatyeyeva, 2021).

It is known that there are two types of corrosion: chemical corrosion (dry corrosion) and electrochemical corrosion (aqueous corrosion) (Ramanathan, 1997).

In electrochemical corrosion, the most common form of chemical attack on metals, chemical reactions occur that involve the transfer of charge or electrons through an interface or electrolyte, which are the cases of corrosion observed in metallic materials when in the presence of electrolytes, and the electrolyte may be solubilized in water or molten. The most common cases are: corrosion in water or aqueous solutions; atmospheric corrosion; corrosion in soil; corrosion in molten salts (Askeland & Wright, 2016).

In chemical corrosion, there are direct chemical reactions between the metallic or non-metallic material and the corrosive medium, and no electric current is generated. The most common cases are: corrosion of metallic material, at high temperatures, by gases or vapors and in the absence of humidity, called dry corrosion; corrosion in water-free organic solvents; corrosion of non-metallic materials (Gentil, 2022).

Corrosion attacks metals and alloys found in oil and gas pipelines, power grid communication cables, ship mooring piers, fuel storage tanks, means of transportation, buildings, electronic devices, among others (Tolentino, 2015).

In each country, experts assess the total economic losses (direct and indirect) caused by corrosion, which amount to around 1 a 5 % of GDP (Matlakhov & Matlakhova, 2021).

In Brazil, it is estimated that the total cost of corrosion is between 3.5% and 4.0% of GDP, with the possibility of saving 20% if corrosion could be combated through the use of more resistant materials and the adoption of appropriate techniques, from the design phase to the maintenance of structures and equipment (Gentil, 2022).

Corrosion can compromise the safety of operational equipment, causing failures (with catastrophic consequences) in, for example, pressure vessels, boilers, metal containers for toxic chemicals, turbine blades and rotors, bridges, aircraft components and automotive steering mechanisms (Revie & Uhlig, 2008).

Most metals and alloys are subject to oxidation or corrosion to a greater or lesser degree in a wide variety of environments (Callister & Rethwisch, 2018). According to Santos (2015), the means of corrosion can be numerous, but the incidence of corrosion in aqueous media is higher.

Corrosion can occur in different forms, depending on the metal, the medium and the corrosion conditions. All the forms of corrosion encountered in practice can be classified according to the corrosion mechanism, the corrosion morphology, the nature of the corrosive medium and the stress state of the metal (Figure 1) (Matlakhov & Matlakhova, 2021).

Figure 1 shows a detailed flowchart that classifies the different types of corrosion based on three main criteria: morphology, medium and stresses. This organization allows for a better understanding of the mechanisms involved and makes it easier to identify the specific forms of corrosion that can occur in different environments and operating conditions.

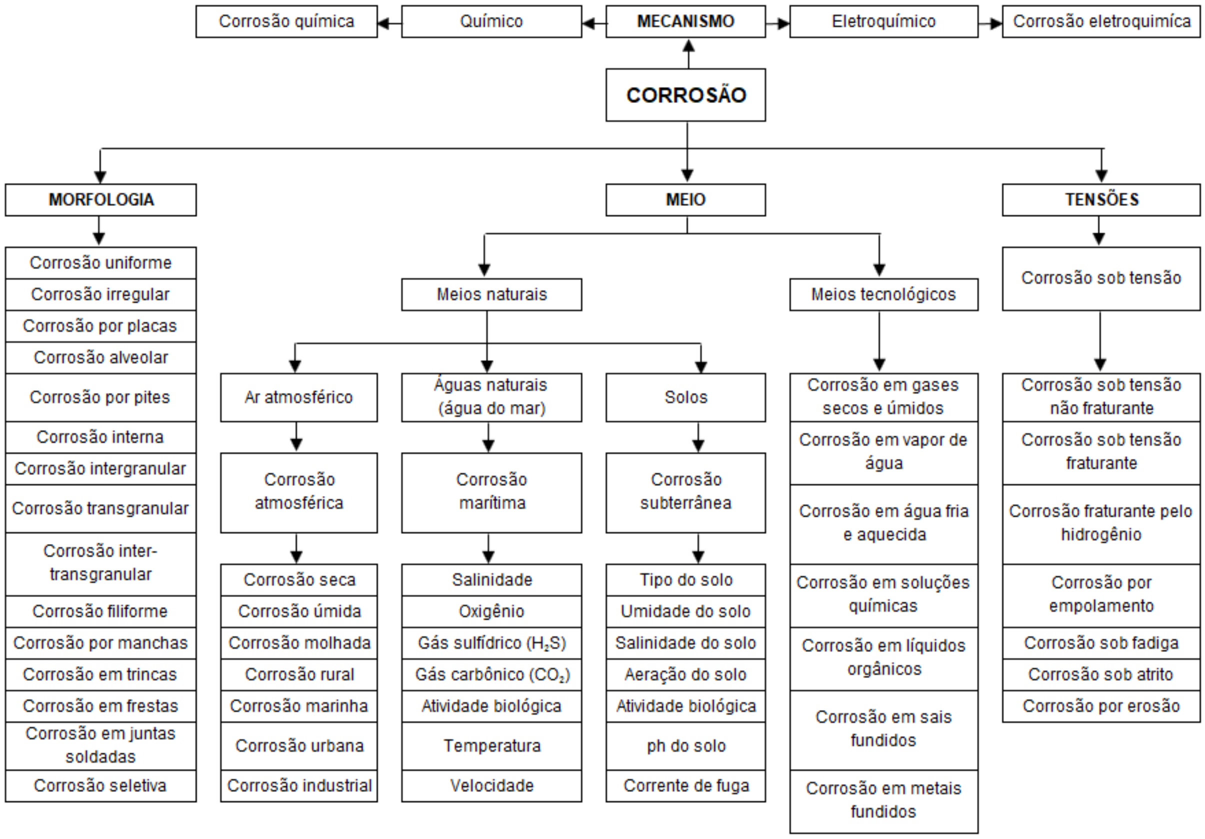

Figure 1 - Classification of forms of corrosion. Source: Matlakhov & Matlakhova, 2021

When evaluating the types of corrosion, it is essential to cover the diversity of phenomena that can compromise the integrity of metallic materials. Among the main types are uniform corrosion, which causes uniform deterioration of the surface; pitting corrosion, which results in small deep holes; crevice corrosion, which occurs in confined areas; intergranular corrosion, which attacks the edges of metal grains; and galvanic corrosion, caused by the combination of two different metals in an electrolyte. In addition, surface corrosion, which affects large metal surfaces in plates; filiform corrosion, which manifests itself in the form of thin, branched filaments; and localized pitting corrosion, which creates rounded cavities in the metal surface, are also important. Hydrogen blistering corrosion, which results in the formation of internal bubbles due to hydrogen absorption, and corrosion around the weld bead, which occurs in areas adjacent to the welds, are critical phenomena to consider. Finally, exfoliation corrosion, which causes the material to separate into layers, is also a significant type. Understanding these distinct forms is crucial for choosing suitable materials and methods for preventing and controlling corrosion (Ramanathan, 1997; Gentil, 2022).

Once the cause and form of corrosion have been discovered, the next step is to determine the best way to reverse the situation. Knowledge of the mechanisms involved in a corrosion reaction is essential for effective corrosion control, as they can suggest the best way to combat it (Lattmann & Alves, 2020).

Corrosion control methods consist of protective coatings, corrosion-resistant metals and alloys, corrosion inhibitors, polymers, anodic and cathodic protection, corrosion control services, corrosion research and development, and education and training (Sastri, 2015).

In all the methods used to protect against corrosion, the economic factor is paramount. Any measure will be economically advantageous if the cost of maintenance decreases, so an economic analysis is necessary to assess which protection method is most advantageous for a particular piece of equipment (Lattmann & Alves, 2020).

According to Yanhua & Jiang (2023), the use of corrosion inhibitors is the most economical and practical means of controlling metal corrosion in different corrosive media.

Corrosion inhibitors are one of the main methods used to reduce corrosion problems in metal installations around the world. One of the most expensive and corrosive installations in chemical plants and refineries is the gas purification system. The most economical and effective method of protection is the addition of inhibitors to the system's closed circulation circuit (Carew et al., 1996).

Corrosion inhibition consists of the addition of chemical products known as corrosion inhibitors, which minimize the extent of corrosion (Sastri, 2011; Souza et al., 2023).

An inhibitor is a substance or mixture of substances which, when present in suitable concentrations in the corrosive environment, reduces or eliminates corrosion. Substances with these characteristics have been widely used as one of the best methods of protection against corrosion, and a lot of research into the use of new compounds for this purpose has been stimulated by various industries (Gentil, 2022). According to Zhang et al. (2022), the application of a corrosion inhibitor is one of the most practical and effective means of inhibiting metal corrosion in a medium.

A corrosion inhibitor can work in two ways. In some situations the added inhibitors can make the corrosive environment to a non-corrosive or less corrosive environment through their interaction with the corrosive species. In other cases, the corrosion inhibitor interacts with the metal surface and, as a consequence, inhibits the corrosion of the metal (Sastri et al., 2007).

According to Gentil (2022), there are different classifications for inhibitors, including those based on composition and behavior. In terms of composition, they can be classified as organic and inorganic, and in terms of their behavior, as anodic, cathodic, oxidizing, non-oxidizing and adsorption-based inhibitors.

Inorganic inhibitors normally work by passivating the metal surface without requiring oxygen. These include chromate and nitrate ions, which can be reduced while oxidizing metal surfaces to form a passive oxide film. Other inorganic compounds require oxygen to work, including phosphates, silicates, borates, tungstates and molybdates. Eliminating the use of compounds that are more toxic to the environment, such as chromates and dichromates, and replacing them with more environmentally friendly chemicals, has been a major change in direction (Roberge, 2019). Most inorganic inhibitors (such as chromates) are no longer useful because they pose a health and safety problem (Forsyth & Hinton, 2014).

Organic inhibitors are chemical compounds that are added to a corrosive medium in order to reduce or inhibit the corrosion process of a metallic material. They are often used in industry to protect metal equipment and structures against corrosion, prolonging their useful life and avoiding financial losses. Organic inhibitors can be obtained from natural sources, such as plant extracts, or chemically synthesized in the laboratory. The most traditional synthetic (organic) corrosion inhibitors are considered environmentally unfriendly due to their high toxicity and bioaccumulation capacity (Quraishi, et al., 2020). Plant extracts are ideal candidates to replace traditional synthetic organic and inorganic corrosion inhibitors, which are expensive and toxic. Plant extracts contain various phytochemical constituents that can easily adsorb and inhibit metallic corrosion (Verma et al., 2018).

The growing concern about the toxicity, biodegradability and bioaccumulation of corrosion inhibitors released into the environment requires corrosion inhibitors to be non-toxic and environmentally friendly (Sastri, 2011).

The environmental problems caused by most chemical products in general, and those used in corrosion protection in particular, have encouraged the development of so-called green chemistry in relation to corrosion inhibitors. The new legislation for chemical substances requires these substances to be environmentally acceptable, with low toxicity to humans. This type of corrosion inhibitor is known as environmentally acceptable, natural, green or ecological inhibitors (Forsyth & Hinton, 2014). Also according to Forsyth & Hinton (2014) the US Environmental Protection Agency, green chemistry consists of chemicals and chemical processes designed to reduce or eliminate negative environmental impacts. The use and production of these chemicals can involve waste reduction, non-toxic components and greater efficiency. Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations.

Natural inhibitors can be extracted from roots, stems, leaves, flowers, fruits, seeds, and other parts of plants. Natural plant extracts have a number of benefits, including being environmentally friendly, non-toxic, easily accessible and comparatively cheaper. They are also biodegradable and free of heavy metals and other toxic substances (Zhang et al., 2022).

Corrosion inhibitors have been used to preserve the integrity of metallic components of plant installations under severe corrosive conditions, which would lead to the failure or reduction of the operating cycle of essential units (Assis et al., 2015).

Plant extracts contain a variety of phytochemical constituents, such as tannins, alkaloids, flavonoids, saponins and other heterocyclic compounds. These phytochemicals have been considered potential corrosion inhibitors. The inhibition mechanism of green corrosion inhibitors depends on heterocyclic organic portions, such as alkaloids, flavonoids, cellulose, tannins and polycyclic molecules, which are useful in film formation on the metal surface (Chauhan et al., 2022). Secondary metabolite compounds contained in plants, such as tannins, alkaloids and saponins, can be used as organic inhibitors (Sari & Nazruddin, 2022).

According to Haida et al. (2015), their study showed that guava has a high antioxidant potential, as it contains a large amount of phenolic compounds, both in the pulp and in the seeds. Plant extracts have become the focus of corrosion inhibitor research due to their low toxicity, easy availability and economical preparation (Mo et al., 2016). According to El-Kady et al. (2017), guava seed extracts are an excellent source of antioxidants, thanks to the phenolic compounds (flavonoids, phenolic acids) present in their composition. These compounds are responsible for the antioxidant activity of guava seed extracts (Kamath et al., 2008; Angulo-López et al., 2021; Silva et al., 2025).

Kumar et al. (2011), affirm the efficiency of *P. guajava* seed extract as a safe, ecological and alternative corrosion inhibitor for carbon steel in acidic media.

Metodology

The mass loss tests and extract preparation were carried out at the Chemistry Laboratory of the Candido Mendes University in Campos dos Goytacazes, RJ. Figure 2 shows the flowchart containing the stages developed in the research.

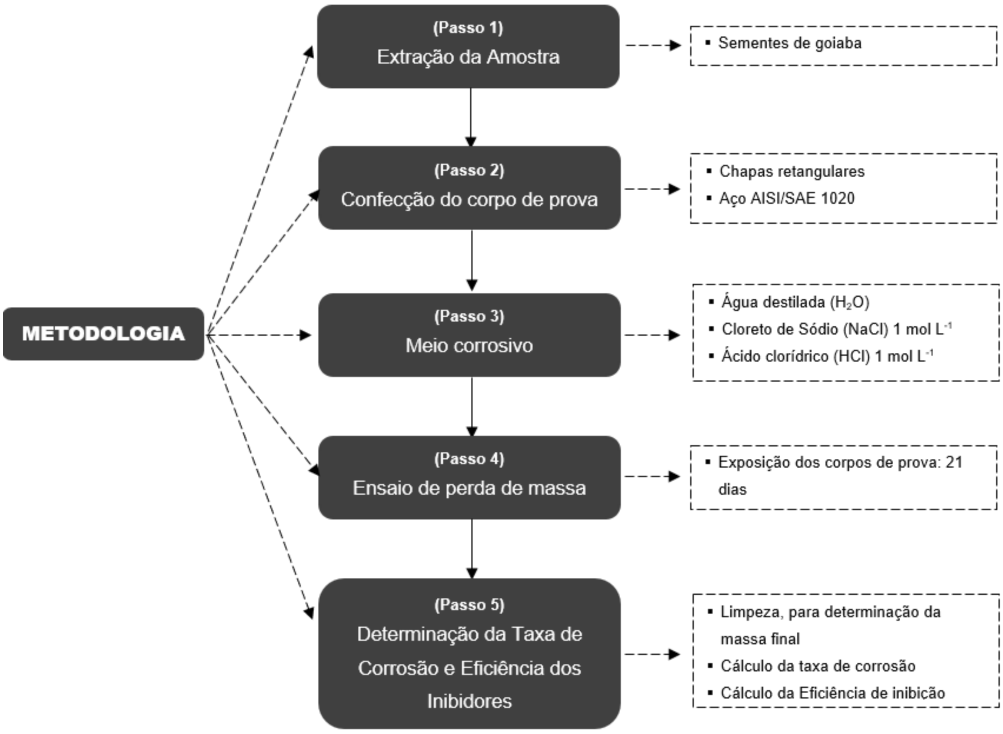

Figure 2 - Flowchart of the mass loss test stages Source: research data

Materials

The materials used in this study include eighteen test specimens, made from rectangular metal sheets with dimensions of approximately 50 ×2 5 mm, a thickness of 3 mm and a central hole of 8 mm in diameter. In addition, guava seeds, distilled water, sodium chloride solution (NaCl) at 1 mol·L^{-1} and hydrochloric acid solution (HCl) at 1 mol-L^{-1} were used. The quantities of liquid reagents and biological materials were determined according to the experimental demand of each test, ensuring reproducibility and control of the experimental conditions.

Methods

Sample extraction

The guava seeds (*Psidium guajava* L.) were removed from the fruit by hand, then washed in running water and dried in the open air. After drying, the seeds were ground into powder (Figure 3).

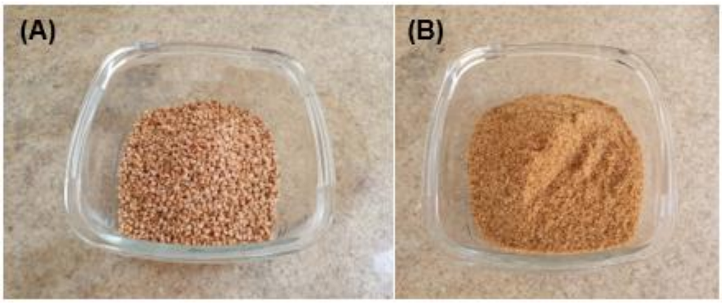

Figure 3 - Guava seeds: (A) before being crushed; (B) after being crushed. Source: research data

Making the Specimen

The specimens were made from rectangular sheets of AISI/SAE 1020 carbon steel, with a total surface area of approximately 30 cm² (Figure 4). These specimens were prepared from a flat bar with a width of 25 mm and a thickness of 2 mm . They were first sanded with water sandpaper of different grain sizes, washed with distilled water and then dried. The initial mass was determined using a precision scale (±0,01 g). A different specimen was used for each immersion time.

Figure 4 - AISI/SAE 1020 carbon steel specimens. Source: research data

To fix the specimens during the tests, a central hole was drilled in each sample using a drill with a diameter of 8 mm. The drilling process was carried out using a DeWalt model DWE1622K bench drill, which is widely used in laboratories and workshops due to its precision, robustness and ease of operation.

Corrosive Medium

Three corrosive media were used in this work: water (H_2O), sodium chloride solution (NaCl) 1 mol·L^{-1} and hydrochloric acid (HCl) 1 mol L^{-1}.

Mass loss test

The test was carried out using 18 specimens, which were previously prepared and weighed on an analytical balance with a precision of ±0.01g, so that their initial masses could be determined. The final masses of the specimens were obtained after 21 days' exposure at room temperature in H_2O, 1 mol·L-1 HCl solution and 1 mol·L 1 NaCl solution, in the absence and presence of concentrations of 1 g L-1 of the inhibitor (Figure 5).

Figure 5 - Corrosion test: (A) start of the test; (B) after 21 days of testing. Source: research data

Corrosion Rate and Effectiveness of Inhibitors

After completing the pre-established immersion time, the metal samples were removed from the corrosive environment and pickled using a steel sponge. After the pickling process, the specimens were washed again in running water, dried and weighed, thus obtaining their final mass.

The speed of the corrosion process (W_{corr}) was expressed by calculating the corrosion rate, in millimeters per year (mm/year), using equation 1 (GENTIL, 2022):

$$W_{corr} = \frac{KM}{Atp} \qquad (1)$$

Where:
K = Constant related to the desired unit of mm/year ($8.76x10^4$), M = Mass loss (g), A = Exposed area (cm²), t = Exposure time (h), ϱ = Specific mass of the material (for carbon steel 7.86 g/cm³).

The Inhibition Efficiency (IE%), according to Gentil (2022), was calculated using equation 2:

$$EI\% = \frac{W_{sem\ extrato} - W_{com\ extrato}}{W_{sem\ extrato}} x100 \qquad (2)$$

Where:

$W_{without\ extract}$= corrosion rate without extract (mm/year) and $W_{with\ extract}$= corrosion rate with extract (mm/year).

Results and Discussion

The mass loss of the specimens immersed in H_2O, in HCl solution NaCl, in the presence and absence of inhibitor, as well as the mass of the plates evaluated at the beginning and end of the test, are shown in Table 1.

Table 1 - Loss of mass of the specimens analyzed

Solution	Inhibitor (guava seed)	Sheets	Mass of plates (g)		Mass Loss
			Home	21 days	
H_2O	No Inhibitor	Sample 1	28,89	28,78	0,11
	No Inhibitor	Sample 2	28,85	28,74	0,11
	No Inhibitor	Sample 3	28,44	28,35	0,09
	1 g L^{-1}	Sample 4	28,87	28,80	0,07
	1 g L^{-1}	Sample 5	29,33	29,25	0,08
	1 g L^{-1}	Sample 6	28,74	28,68	0,06
HCl	No Inhibitor	Sample 7	28,82	17,08	11,74
	No Inhibitor	Sample 8	28,85	17,36	11,49
	No Inhibitor	Sample 9	29,13	17,84	11,29
	1 g L^{-1}	Sample 10	29,03	23,66	5,37
	1 g L^{-1}	Sample 11	28,67	23,45	5,22
	1 g L^{-1}	Sample 12	28,69	25,23	3,46
NaCl	No Inhibitor	Sample 13	28,51	28,46	0,05
	No Inhibitor	Sample 14	28,89	28,79	0,10
	No Inhibitor	Sample 15	28,91	28,83	0,08
	1 g L^{-1}	Sample 16	29,18	29,10	0,08
	1 g L^{-1}	Sample 17	28,53	28,53	0,00
	1 g L^{-1}	Sample 18	29,04	29,01	0,03

Source: survey data

From this data, the corrosion rates and inhibition efficiencies of AISI/SAE 1020 carbon steel immersed in the corrosive media were calculated.

Table 2 shows the corrosion rate results obtained from the mass loss test on 1020 carbon steel in a medium of H_2O, HCl and NaCl, in the absence and presence of the inhibitor (guava seed powder), and their respective efficiencies.

Table 2 - T corrosion rate (Wcorr) and inhibition efficiency (EI) obtained for carbon steelem meio H2O, HCl and NaCl, in the absence and presence of natural inhibitor (guava seed powder), during 21 days of immersion

Solution	Inhibitor (guava seed)	Sheets	Wcorr (mm/year)	Average	EI (%)
H_2O	No Inhibitor	Sample 1	0,0806	0,0760	–
	No Inhibitor	Sample 2	0,0808		
	No Inhibitor	Sample 3	0,0666		
	1 g L^{-1}	Sample 4	0,0514	0,0510	32,90
	1 g L^{-1}	Sample 5	0,0574		
	1 g L^{-1}	Sample 6	0,0442		
HCl	No Inhibitor	Sample 7	8,7075	8,4255	–
	No Inhibitor	Sample 8	8,4118		
	No Inhibitor	Sample 9	8,1572		
	1 g L^{-1}	Sample 10	3,9673	3,4452	59,11
	1 g L^{-1}	Sample 11	3,8241		
	1 g L^{-1}	Sample 12	2,5442		
NaCl	No Inhibitor	Sample 13	0,0370	0,0561	–
	No Inhibitor	Sample 14	0,0728		
	No Inhibitor	Sample 15	0,0586		
	1 g L^{-1}	Sample 16	0,0589	0,0270	51,95
	1 g L^{-1}	Sample 17	0,0000		
	1 g L^{-1}	Sample 18	0,0220		

W_{corr}= Corrosion Rate , EI = Inhibition Efficiency. Source: research data

Based on the results shown in Table 2, it can be seen that the presence of the inhibitor showed a reduction in the corrosion rate of the samples compared to the samples without inhibitor. This can be confirmed by the graphs in Figures 6, 7 and 8, which show the corrosion rates obtained for the samples immersed in H_2O, HCl and NaCl solutions respectively. These results indicate that guava seeds have the ability to inhibit the corrosion of 1020 carbon steel.

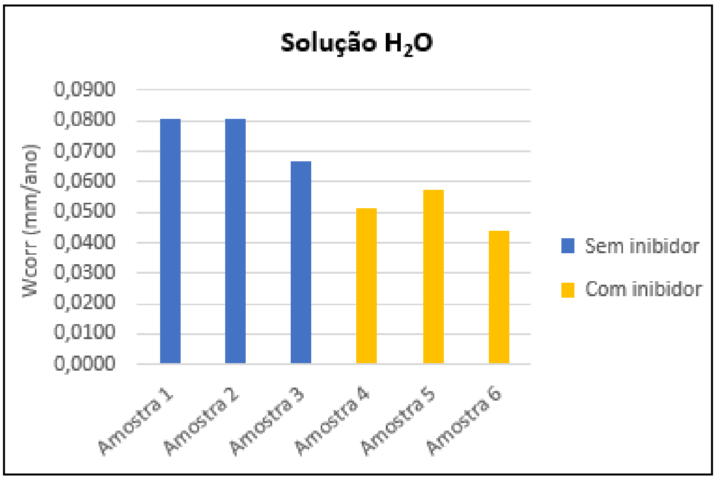

Figure 6 - Graph of the corrosion rate of samples in $H_{(2)}$ O solution Source: research data

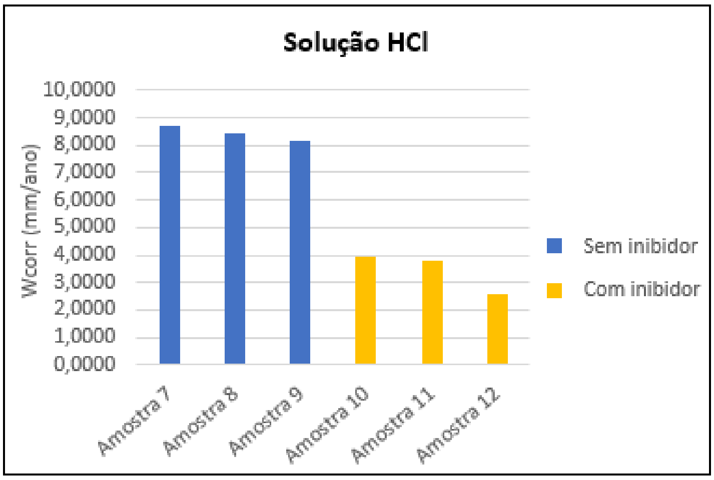

Figure 7 - Graph of the corrosion rate of the samples in HCl solution. Source: research data

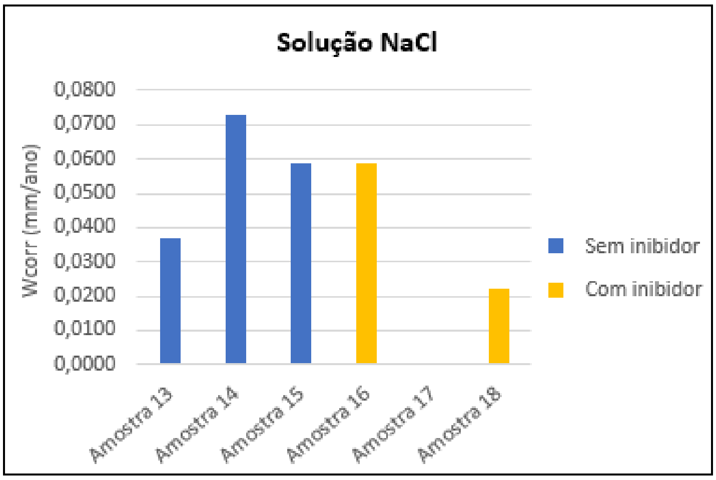

Figure 8 - G graph of the corrosion rate of the samples in NaCl solution. Source: research data

In terms of inhibition efficiency, the corrosion inhibitor was more effective in acidic media, with an efficiency of 59.11%, compared to neutral media (Figure 9), taking as parameters the results obtained in the mass loss tests of the specimens analyzed (Table 1).

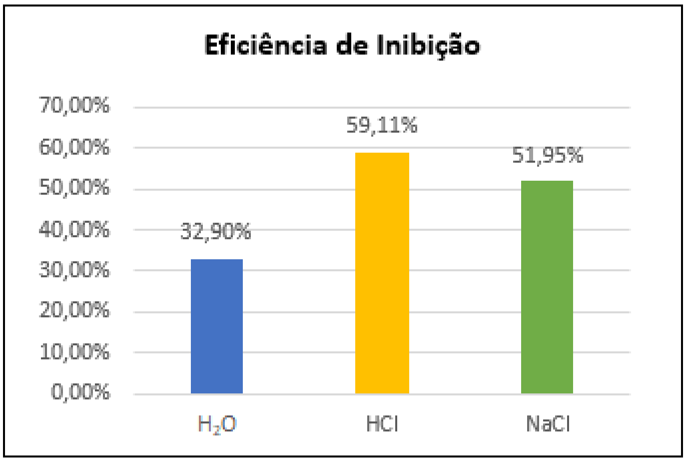

Figure 9 - G graph of inhibition efficiency. Source: research data

Photographic records were taken of all the corrosion tests and specimens used before and after 21 days.

All the tests reported from Figure 10 to Figure 22 a image (A) shows the specimen at the start of the test. In the corrosion test in H_2O solution (Figures 10 and 11), Figure 10 B shows the presence of corrosion products around the specimens, while Figure 11-B does not show the formation of corrosion products. When analyzing the surface of the specimens in Figure 12-B, it is possible to see marks of the corrosion product (with a darker color and irregular texture). In Figure 13-B, no corrosion marks can be seen on the specimens.

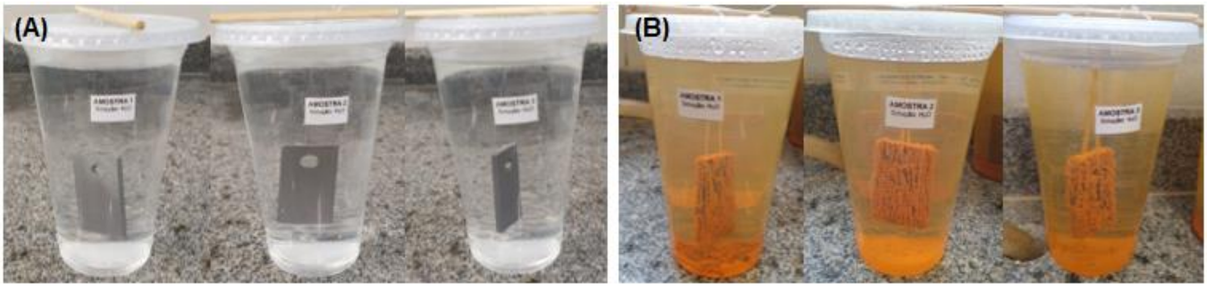

Figure 10 - E corrosion test in H_2O solution without inhibitor: (A) start of test; (B) after 21 days of testing. Source: research data

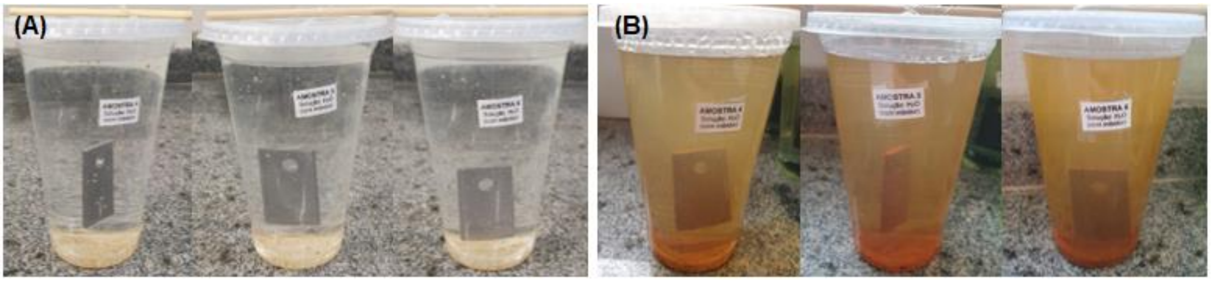

Figure 11 - E corrosion test in H_2O solution with inhibitor: (A) start of test; (B) after 21 days of testing. Source: research data

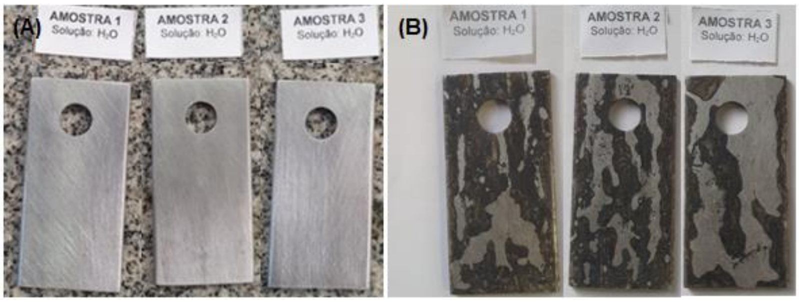

Figure 12 - Specimen used in the test in H_2O solution without inhibitor: (A) before the test; (B) after 21 days of testing. Source: research data

Figure 13 - Specimen used in the test in H_2O solution with inhibitor: (A) before the test; (B) after 21 days of testing. Source: research data

In the corrosion test in HCl solution (Figures 14 and 15), which proved to be the most aggressive medium due to its acidic nature, with a corrosion rate of more than 8 mm/year (Table 2), a corrosive attack can be clearly seen in Figure 14-B. The presence of corrosion products around the specimens, as well as a dark coloration and the existence of corrosion residues can be observed at the bottom of the container. Figure 15-B shows no corrosion products, no change in the color of the specimens and no corrosion residues at the bottom of the container, showing that the presence of the inhibitor reduced the corrosive attack. However, hydrogen blistering corrosion was observed (Figure 16), where hydrogen penetrates the metallic material and, due to its small volume, diffuses rapidly into regions with discontinuities, such as inclusions and voids, transforming into H_2, exerting pressure and causing the formation of bubbles (blistering).

When analyzing the surface of the specimen in Figure 17-B, it is possible to see uniformly aggressive corrosion, while Figure 18-B shows less aggressive corrosion compared to Figure 17-B.

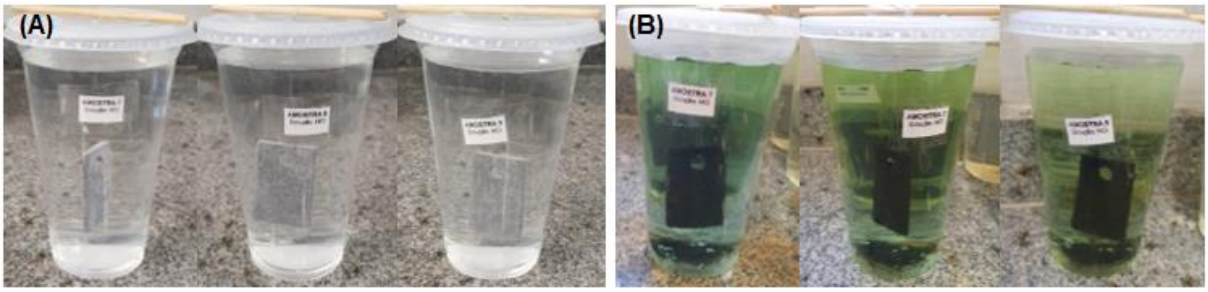

Figure 14 - E corrosion test in HCl solution without inhibitor: (A) start of the test; (B) after 21 days of testing. Source: research data

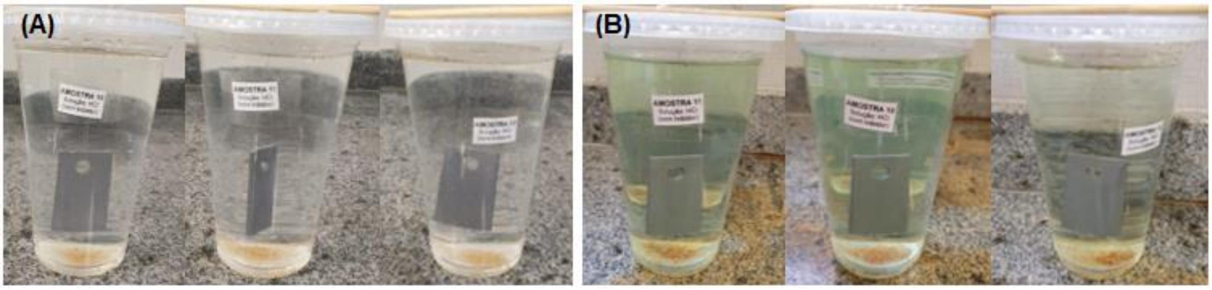

Figure 15 - E corrosion test in HCl solution with inhibitor: (A) start of test; (B) after 21 days of testing. Source: research data

Figure 16 - Corrosion by Hydrogen Blistering. Source: research data

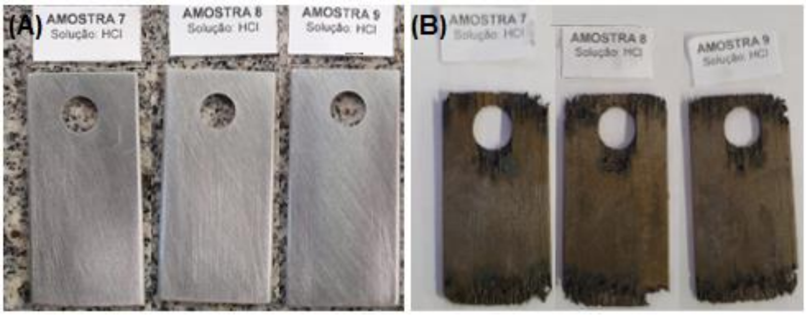

Figure 17 - Specimen used in the test in HCl solution without inhibitor (A) before the test; (B) after 21 days of testing. Source: research data

Figure 18 - Specimen used in the test in HCl solution with inhibitor: (A) before the test; (B) after 21 days of testing. Source: research data

In the corrosion test in NaCl solution (Figures 19 and 20), Figure 19-B shows the presence of corrosion products around the specimens, while Figure 20-B does not show the formation of corrosion products. When analyzing the surface of the specimens in Figure 21-B, it is possible to see corrosion product marks. In Figure 22-B, no corrosion marks can be seen.

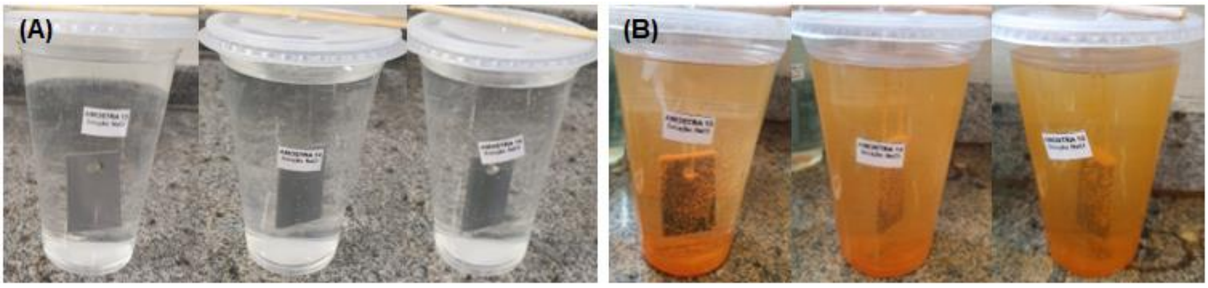

Figure 19 - E corrosion test in NaCl solution without inhibitor: (A) start of test; (B) after 21 days of testing. Source: research data

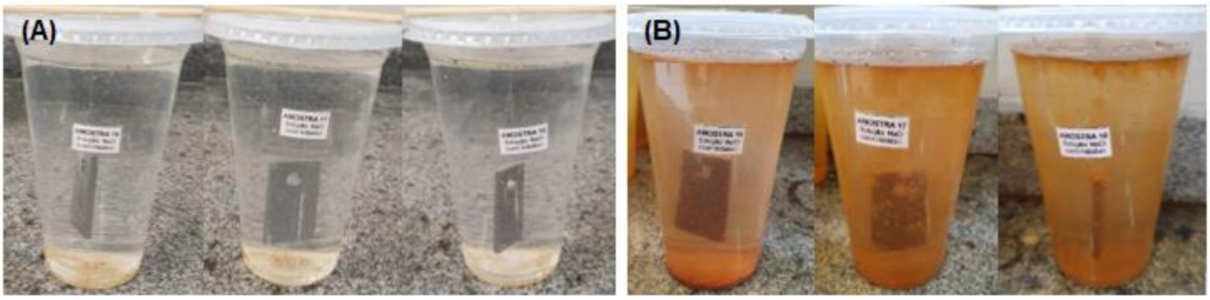

Figure 20 - E corrosion test in NaCl solution with inhibitor: (A) start of test; (B) after 21 days of testing. Source: research data

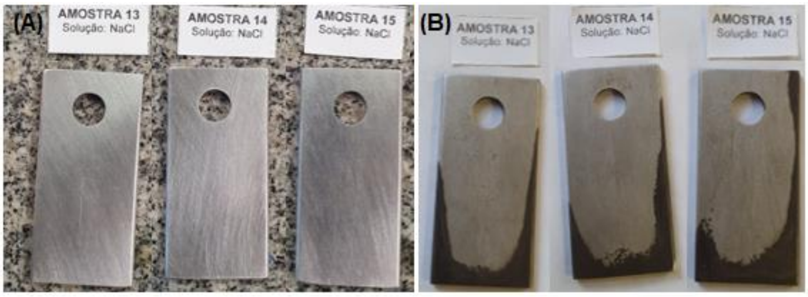

Figure 21 - Color specimen used in the test in NaCl solution without inhibitor: (A) before the test; (B) after 21 days of testing. Source: research data

Figure 22 - Color specimen used in the test in NaCl solution with inhibitor: (A) before the test; (B) after 21 days of testing. Source: research data

Conclusion

The analysis of corrosion on carbon steel, using the mass loss test, showed a significant reduction in the rate of corrosive attack in the presence of guava seed powder, especially in an acidic environment. The results indicate that the natural inhibitor acted effectively, providing considerable protection to the metal surface when compared to the test carried out in the absence of the additive.

Based on the results, it is possible to state that guava seeds, in powder form, can act as a corrosion inhibitor for AISI/SAE 1020 carbon steel. The results obtained in the mass loss tests showed a reduction in the mass loss and corrosion rate of the samples when exposed to H_2O, HCl solution, and NaCl solution containing guava seed powder. This indicates that guava seeds have corrosion-inhibiting properties. Analysis of the results obtained showed the antioxidant capacity of the compounds present in guava seeds, which contribute significantly to protecting the material against corrosive processes.

These results are highly relevant, as they point to the feasibility of using natural inhibitors, such as guava seeds, to protect against corrosion in industrial applications. The use of natural inhibitors represents a more sustainable and economically viable alternative to traditional chemical inhibitors, with a positive impact on industry.

Since carbon steel is a highly cost-effective material, it is widely used in mechanical components such as gears, shafts, crankshafts, among others, which always require anti-corrosion maintenance. Guava seed is therefore a possible raw material that is easy to acquire and non-toxic to the environment as a natural corrosion inhibitor for 1020 carbon steel in acidic and neutral environments.

The inhibition efficiency of guava seed powder was 59.11% in HCl medium, 51.95% in NaCl medium and 38.90% in H_2O medium. However, it is important to note that more research and studies are needed to fully understand the mechanisms of guava seed corrosion inhibition and improve its efficiency as a corrosion inhibitor. In addition, it is necessary to consider other factors, such as the concentration and exposure time of the guava seed extracts, in order to determine the ideal application conditions.

Finally, it can be concluded that guava seeds, in powder form, can act as a corrosion inhibitor for carbon steel in acidic and neutral environments.

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