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RESEARCH

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# *Arachis hypogaea*'s concentration effect on AISI 1020 carbon steel for corrosion protection

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## Abstract

The effects of inhibitor concentration on the corrosion rate and inhibition efficiency of AISI 1020 steel in an acidic and alkaline environment were investigated by means of weight loss measurement at an interval of 7 days and 14 days. To carry out this investigation, the *Arachis hypogaea* hull was extracted and concentrated in various weight percentages. The inhibition efficiency increased with the increased concentrations of AISI 1020 steel that were immersed in acidic and alkaline solution in the absence and presence of varying inhibitor concentrations of *Arachis hypogaea* hull extracts. The corrosion behavior, including the corrosion rate, is meticulously characterized through the corrosion rate analysis. The results showed that there is an increase in inhibition efficiency with an increase in inhibitor concentration and that there is a decrease in inhibition efficiency with an increase in immersion time. The organic inhibitor (*Arachis hypogaea* hull) produced the best inhibition efficiency of 96.4% at a 30% concentration. From the result obtained, *Arachis hypogaea* hull extracts revealed that it is best suited for inhibition of corrosion of mild steel in both acidic and alkaline environments. The goal of this research paper is to develop a comprehensive understanding of the corrosion inhibition and adsorption mechanisms associated with the implementation of the *Arachis hypogaea* hull as a natural corrosion inhibitor.

**Keywords:** *Arachis hypogaea*, AISI 1020 carbon steel, Corrosion inhibitors, Corrosion rate, Inhibiting efficiency

## Introduction

Corrosion is a severe condition that often deteriorates the surface of carbon steel. The occurrence of corrosion in carbon steel is unavoidable as most of the applications of steel are mainly exposed to an acidic and alkaline environment [1]. The occurrence of corrosion in carbon steel resulted in effects such as significant surface deterioration, catastrophic equipment failure, performance degradation, and many more [2]. Since corrosion largely deteriorates the performance of mild steel, numerous prevention methods have been implemented such as alloying addition, metal impurity content reduction, surface coating and treatment, metal plating, cathodic protection, and many more [3, 4]. A widely recognized and the simplest and most cost-effective method for preventing corrosion is the development of corrosion inhibitors. These inhibitors work by forming a protective barrier on the metal surface through a chemical reaction, effectively reducing the occurrence of corrosion [5].

However, the problem with the current corrosion inhibitors is that it is mainly produced using toxic and harmful material that can be hazardous to humans and the environment. Recent studies demonstrated that prolong exposure to inorganic corrosion inhibitors is harmful to human health and noxious to plants and animals and has adverse effect to the ecology of the environment and on both surface and groundwater quality [4, 5]. This has prompted the search for green corrosion inhibitors. It would be beneficial if the current corrosion inhibitors could be replaced by a material that uses less chemical and a more natural and safe material to reduce the bad effect to the environment and human health.

Natural corrosion inhibitors are extracted mainly from part of plant or animal which inherent an active compound that will interfere with cathodic or anodic reaction, thus creating an ability to decrease the corrosion occurrence [6, 7]. The organic compound must possess inhibiting ability that depended on presence of active heteroatoms, such as nitrogen, oxygen, sulfur, and phosphorous, and phytochemical or physiochemical compositions, such as tannins, alkaloids, and amino acids [8]. Plant parts such as husk, leaves, flower, root, peel, and essential oil contained this type of molecule and were successfully introduced as natural corrosion inhibitors. The improvement of corrosion was optimized when the inhibiting efficiency of the natural corrosion inhibitors and adsorption energy were over 80% [9, 10]. Previous literature proved that the inhibition efficiency up to 80% can be attained with the increment of the inhibitor concentration [11–13]. Another potential natural corrosion inhibitor is *Arachis hypogaea* or groundnut. *Arachis hypogaea* oil had the effect of reducing corrosion in acidic environments at 316 stainless steels [14] and mild steel [15] as the adsorption energy and inhibiting efficiency increased to more than 80–90% with the increment of the oil concentration. *Arachis hypogaea* oil contained heteroatomic atoms and compounds such as saponins, glycosides, alkaloids, terpenoids, quinones, and steroids that will promote covalent or electrostatic interaction, forming protective film layers that will facilitate corrosion resistance [16, 17].

The inhibiting efficiency of a corrosion inhibitor determines its capability to slow down or stop the corrosion process. A high inhibiting efficiency indicates that the inhibitor is effective in reducing the corrosion rate, while a low inhibiting efficiency suggests that the inhibitor is less effective. Several studies have been conducted to investigate the inhibiting efficiency and adsorption energy of natural corrosion inhibitors [18, 19]. Highly efficient corrosion inhibitors have been achieved by means of these substances from sustainable, ecological, and environmentally friendly sources, with plant extracts being a prominent group [20].

Nonetheless, there has been a scarcity of research focusing on the utilization of waste materials from the *Arachis hypogaea* hull. An extract from *Arachis hypogaea* hull is a solution composed by the active principle of its shell (Fig. 1) and a certain medium acting as solvent. *Arachis hypogaea* hull is a lignocellulosic material composed of cellulose (44.8%), hemicellulose (5.6%), and lignin (36.1%) with a complex fibrous structure [21].

**Fig. 1** *Arachis hypogaea* hull

Plant extracts contain various organic compounds such as tannins, alkaloids, and flavonoids that have been found to inhibit corrosion. *Arachis hypogaea* hull containing high tannin content [22] alkaloids and flavonoids has been reported [23] in literature, hence giving it an advantage for this study.

In summary, inhibiting efficiency is found to be one of the essential parameters for evaluating the effectiveness of a corrosion inhibitor, and understanding these parameters for *Arachis hypogaea* hull waste as a natural corrosion inhibitor is crucial in developing effective and sustainable corrosion inhibitors for AISI 1020 steel. Optimistically, the development of natural corrosion inhibitors from *Arachis hypogaea* hull will not only effectively reduce the corrosion of low-carbon steel but also preserve the environment as well as introduce novel application for *Arachis hypogaea* hull which are currently considered as waste. Thus, in this study, this new type of corrosion inhibitors will be explored with the objective to reduce the corrosion occurrence but using a more natural source.

## Materials and methods

### AISI 1020 sample preparation

AISI 1020 steel was prepared by cutting the AISI 1020 steel into the desired sample size using appropriate cutting tools. The cut samples undergo grinding process to achieve a smooth and uniform surface. This step ensures that any surface irregularities or imperfections are removed. Then, the samples are polished using diamond solutions with particle sizes of 1 μm and 3 μm. To remove any contaminants or residue from the preparation process, the polished samples are cleaned using acetone. After the cleaning process, the samples are dried using hot air to ensure complete removal of any residual solvent or moisture. By following these preparation steps in accordance with ASTM E3 standard, the AISI 1020 steel samples are properly processed, ensuring a consistent and clean surface for accurate and reliable testing of corrosion behavior or other desired properties.

### *Spectrometer analysis*

A spectrometer test provides results by measuring the interaction between the sample and electromagnetic radiation. The results are obtained in the form of a spectrum, which is a plot of the intensity of the transmitted or absorbed radiation as a function of the wavelength or frequency. The chemical compositions for AISI 1020 sample are stated as shown in Table 1.

## Extraction of natural inhibitors

The waste from *Arachis hypogaea* hull is cleaned and washed using distilled water to remove unwanted contaminants. It is then dried in the furnace at a temperature of 110 °C for approximately 2 h to remove the moisture. It is then milled up to 43 mesh size and sieves. The ground powder then undergoes extraction process by dispersing the powder in ethanol with 90% purity using the Soxhlet extractor. One hundred milliliters ethanol is added to different weight percentages of *Arachis hypogaea* which are 10%, 20%, and 30% inside the Soxhlet extractor beaker. The solvent (ethanol) is then heated to boiling temperature of no less than 78 °C for it to reflux for 6 h. The rotary evaporator will then be used to obtain the concentration of the *Arachis hypogaea* solution with 40 °C and up to 80% reduction.

## Corrosion test

The corrosion behavior of the materials will be carefully examined in two distinct environments: an acidic environment employing a 1 M concentration of hydrochloric acid and an alkaline environment also with a 1 M concentration of sodium hydroxide. To evaluate the corrosion rates, a weight loss test will be conducted, to compare the samples before and after the introduction of *Arachis hypogaea* concentration. The effectiveness of the inhibitor will be assessed by testing three different percentages (10%, 20%, and 30%) of its content. In the immersion test, the samples will be immersed for specific durations (7 days and 14 days) to simulate prolonged exposure to corrosive environments. After the immersion period, the visual appearance of the materials will be assessed to observe any visible changes or corrosion effects.

Weight loss tests were conducted under total immersion using a 100-ml capacity beaker containing 1 M of both acidic and alkaline environments. The AISI 1020 carbon steels were weighed and dropped in the beaker and were retrieved with time variables of 7 days and 14 days. After each exposure time, the sample steel was removed, washed thoroughly to remove the corrosion product with abrasive paper, rinsed with distilled water, and then dried in acetone. The carbon steel was re-weighed to determine the weight loss in grams, by the difference of carbon steel weight before and after immersion. Weight loss was calculated by finding the difference between the weight of each coupon before and after immersion as shown in Eq. (1)

**Table 1** AISI 1020 carbon steel composition

| Grade | Carbon | Manganese | Silicon | Phosphorous | Sulfur | Nickel | Iron |
|---|---|---|---|---|---|---|---|
| AISI 1020 | 0.18 | 0.80 | 0.36 | 0.003 | 0.002 | 0.06 | 98.6 |

$$\Delta W = W_b - W_a \tag{1}$$

where $W_b$ is the weight before immersion and $W_a$ is the weight after immersion. The corrosion rates (mm/year) were determined and calculated using Eq. (2)

$$\mathrm{CR} = (\Delta W)/(At) \tag{2}$$

where $\Delta W$ is the weight loss (g) after exposure time ($t$, days), $A$ is the area of the specimen (cm.$^2$), and $t$ is the time of exposure in days. Inhibition efficiency was calculated using Eq. (3)

$$IE\% = ((W_0 - W_1)/W_0) \times 100 \tag{3}$$

where $W_1$ and $W_0$ are the weight loss in the presence and absence of inhibitor, respectively.

## Results and discussion

### Fourier transform infrared spectroscopy (FTIR) analysis

FTIR spectroscopy model Vertex 70 with Hyperion series was utilized to indicate the synthesized *Arachis hypogaea* extract. Figure 2 displays the FTIR spectra of the extract, providing valuable information about its molecular composition and functional groups. The absorption of inhibitor molecules to the surface of iron is significantly influenced by the presence of functional groups and heteroatoms, making it a critical factor in inhibiting corrosion. The infrared spectra, as shown in the figure, reveals the existence of various functional groups contained by the *Arachis hypogaea* extract.

Inside the composite, a broad band covering from 3600 to 3000 cm$^{-1}$ was observed in the FTIR spectra. This indicates the occurrence of multiple functional groups displaying absorption in this frequency range. The presence of the carbonate group drew attention by the bands observed around 999 cm$^{-1}$, which indicate the stretching vibrations specific to carbonate group. These absorption bands provide evidence of the existence of carbonate functional groups within the *Arachis hypogaea* extract.

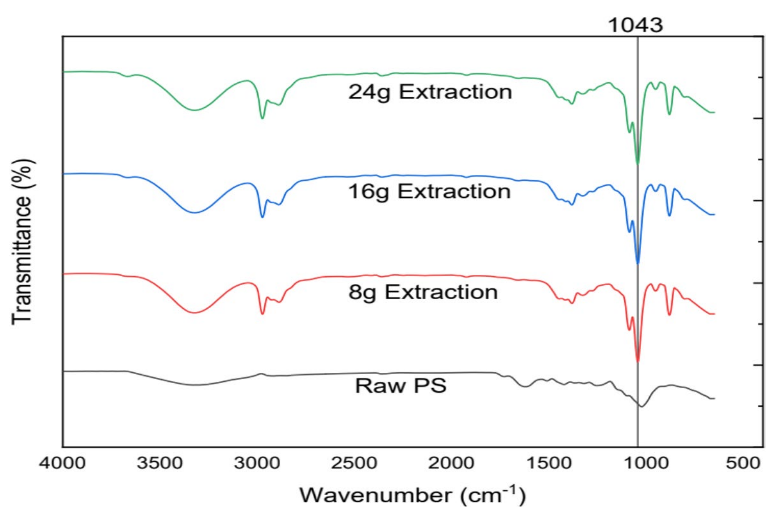



**Fig. 2** FTIR spectrum for *Arachis hypogaea* extract

Besides that, the FTIR spectra also demonstrated bands at 1043 $cm^{-1}$, which correspond to the bending vibrations of the $SiO_2$ silica group. These bands confirm the presence of the carbonate group, as the interaction between the carbonate and silica groups leads to the observation of these bending vibrations.

## Corrosion rate and inhibiting efficiency

Figure 3 presents the results concerning the corrosion rates and inhibiting efficiency of AISI 1020 samples in an alkaline and acidic environment with respect to different immersion times and concentrations of corrosion inhibitors. In the absence of corrosion inhibitors in the alkaline environment, the average corrosion rate of the AISI 1020 samples was recorded at 0.0892536 mm/year.

Conversely, under an acidic environment, the corrosion rate was recorded at 0.276108 mm/year. However, when a 10% concentration of corrosion inhibitors was applied to the alkaline solution, the average corrosion rate decreased to 0.0070632 mm/year. The same occurrence happens for acidic solution where the corrosion rate decreases significantly to 0.083474 mm/year. This reduction indicates a significant decrease in corrosion occurrence by approximately 92.086% and 68.767%, respectively. As the concentration of corrosion inhibitors escalated to 20% and 30%, the corrosion rate in an alkaline environment experienced further reduction to 0.0051368 mm/year and 0.0032106 mm/year, respectively. The same situation transpired in an acidic environment. As the concentration of corrosion inhibitors escalated to 20% and 30%, the corrosion rate in an acidic environment experienced further reduction to 0.043022 mm/year and 0.0314635 mm/year, respectively.

It can be concluded that increasing the concentration of corrosion inhibitors resulted in a reduction of corrosion rate, with a variation of 2.98% observed. Nevertheless, when the immersion time was increased from 7 to 14 days, the corrosion rate of AISI 1020 steel showed an increase with a variation of 18.745%. This implies to the continued exposure to the corrosive environment which led to a faster corrosion process. Overall, the results from both figures highlight the effectiveness of *Arachis hypogaea* extract as corrosion inhibitors in reducing the corrosion rate of AISI 1020 steel. Increasing the concentration of inhibitors leads to further reduction of corrosion rate, while longer immersion times had a negative effect on the corrosion resistance of the steel.

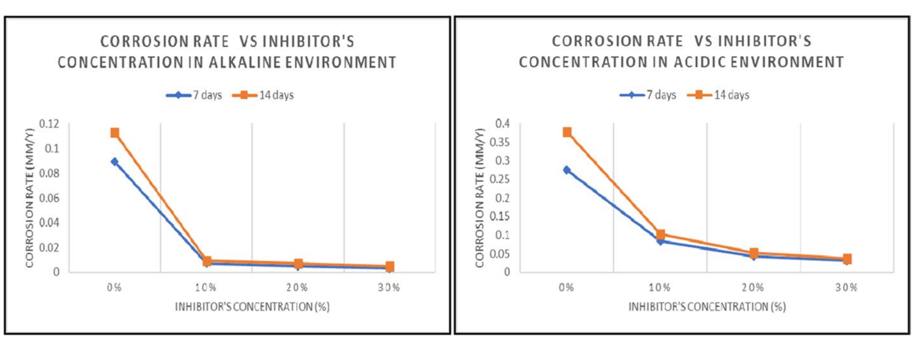



**Fig. 3** Corrosion rate versus inhibitor's concentration in both environment

The inhibiting efficiency of AISI 1020 samples with respect to different concentrations of corrosion inhibitors is shown in Fig. 4. It was found that the inhibiting efficiency improves with a concentration of corrosion inhibitors. This is because the higher concentration of corrosion inhibitors increases the adsorption energy, therefore resulting in optimum inhibition efficiency.

The highest inhibiting efficiency was attained by the sample immersed in sodium hydroxide (NaOH) with 30% inhibitor's concentration with the value of 96.4% while the lowest inhibiting efficiency was attained by the sample immersed in hydrochloric acid (HCl) with 10% inhibitor's concentration with the value of 69.76%. This shows an approximately 27.63% difference. However, as the immersion time increases, the inhibiting efficiency of the AISI 1020 samples is found to be decreasing. The reason is that cathode action reduces oxygen from the air, resulting in formation of hydroxide iron (OH). When the iron hydroxide forms and precipitates, the hydroxide quickly oxidizes to form rust. This resulted in reduction of inhibition efficiency and corrosion rate.

## Macrostructure

The findings presented in Tables 2 and 3 provide insights into the macrostructure of AISI 1020 steel under different conditions. The image was captured using 60 MP Ultrawide Autofocus Camera with macro mode. The steel samples in Table 3 were immersed in a NaOH solution with different concentrations of corrosion inhibitors. When the steel samples were exposed to an alkaline environment, severe chipping and spalling were observed, resulting in noticeable corrosion with a dark gray appearance. As the concentration of corrosion inhibitors increased, the visibility of corrosion occurrence decreased. The initial dark gray color changed into lighter shades of gray and silver, indicating reduced corrosion occurrence and improved surface protection. Additionally, the extension of the immersion period to 14 days increased the visibility of the corrosion substrate, indicating the progression of corrosion over time. In Table 3, the macrostructure of AISI 1020 steel was observed under different concentrations of corrosion inhibitors while being immersed in a HCl solution. The corrosion substratum of the steel was highly visible compared to the sample in NaOH. The detection of corrosion pitting on the samples became less obvious when higher concentrations of corrosion inhibitors were used. The comparison between the samples immersed in an alkaline solution (NaOH) and an acidic solution (HCl) revealed

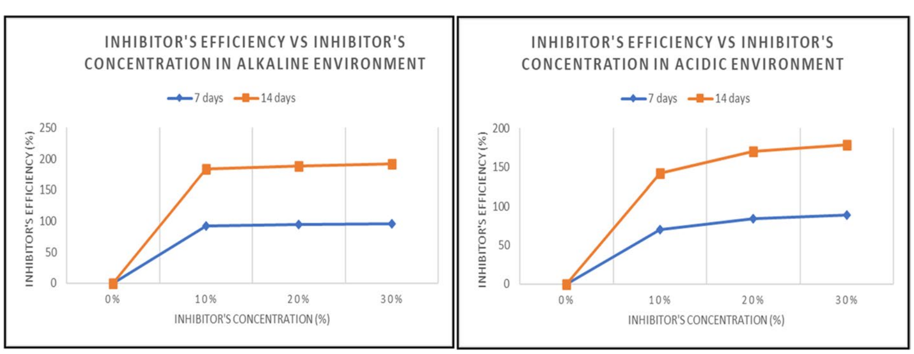



**Fig. 4** Inhibitor's efficiency versus inhibitor's concentration in both environment

**Table 2** Macrostructure of AISI 1020 sample in alkaline environment for 7 days and 14 days

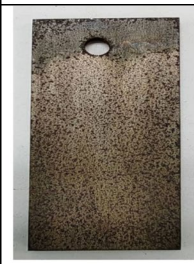
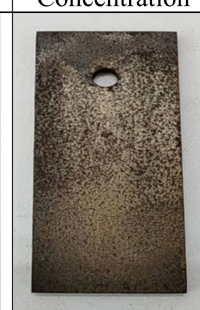
| SAMPLE AISI 1020 | 0% Concentration | 10% Concentration | 20% Concentration | 30% Concentration |
|---|---|---|---|---|
| 7 DAYS |  |  |  |  |
| 14 DAYS |  |  |  |  |

**Table 3** Macrostructure of AISI 1020 sample in acidic environment for 7 days and 14 days

| SAMPLE AISI 1020 | 0% Concentration | 10% Concentration | 20% Concentration | 30% Concentration |
|---|---|---|---|---|
| 7 DAYS |  |  |  |  |
| 14 DAYS |  |  |  |  |

that the AISI 1020 steel samples subjected to the alkaline solution experienced a lower occurrence of corrosion. These observations highlight the effectiveness of corrosion inhibitors in reducing the occurrence of corrosion and provide surface protection for AISI 1020 steel, with higher concentrations of inhibitors yielding better results.

## Conclusions

As a conclusion, two main observations can be made with regard to the relationship between the concentration of corrosion inhibitors and their impact on AISI 1020 mild steel. First, the increment of corrosion inhibitor's concentration resulted in a lower corrosion rate of AISI 1020 mild steel. The experimental results showed that increasing the concentration of corrosion inhibitors led to a significant reduction in the corrosion rate of the AISI 1020 steel. It can be concluded that higher concentrations of corrosion inhibitors effectively inhibited the corrosion process, leading to lower corrosion rates in the mild steel.

Contradicting the trend observed in inhibiting efficiency where even with the decreasing corrosion rates upon higher inhibitor concentrations, the trend observed in inhibiting efficiency showed an improvement with the increment of corrosion inhibitor's concentration. The experiment results demonstrated that as the concentration of corrosion inhibitors increased, the inhibiting efficiency improved. This means that higher inhibitor concentrations resulted in a more effective protection against corrosion, despite the slightly diminishing returns in terms of corrosion rate reduction. This indicates that the inhibitors' ability to inhibit the corrosion process was enhanced with higher concentrations.

### Abbreviations

| | |
|---|---|
| AISI 1020 | Low-carbon steel |
| ASTM E3 | American Testing and Materials Authority Standard Guide for Metallographic Samples |
| °C | Degree Celsius |
| $W_b$ | Weight before immersing |
| $W_a$ | Weight after immersing |
| ΔW | Weight loss |
| *At* | Area of sample (*A*) multiply with times (*t*) day |
| M | Molar |
| FTIR | Fourier transform infrared spectroscopy |
| HCl | Hydrochloric acid |
| NaOH | Sodium hydroxide |
| $OH^+$ | Hydroxide ion |
| O | Oxygen |
| N | Nitrogen |
| IE% | Inhibitor efficiency |
| pH | Potential of hydrogen |
| $H_2SO_4$ | Sulfuric acid |
| $SiO_2$ | Silicon dioxide |
| CR | Rate of corrosion |
| mm/year | Millimeters per year |

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### Authors' contributions
All authors make equal contributions in the proposed research according to their expertise. All authors have read and approved the manuscript.

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### Availability of data and materials
Datasets used during the current study are available from the corresponding author on reasonable request.

## Declarations

### Competing interests
The authors have declared no conflicts of interest.

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