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'STUDY ON EFFECTIVENESS OF COFFEE POWDER AS A CORROSION INHIBITOR ON MILD STEEL'

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ABSTRACT:

Corrosion is a significant concern across various industries, resulting in substantial economic losses and safety risks. While traditional corrosion inhibitors are effective, they often contain toxic chemicals that pose environmental hazards. Consequently, there is increasing interest in eco-friendly and sustainable alternatives. The use of plant-based extracts as corrosion inhibitors has emerged as a preferred and widely adopted approach for preventing metal corrosion in acidic environments due to their environmental benefits.

In this study, coffee powder extract was evaluated as a corrosion inhibitor for mild steel in a 0.1M hydrochloric acid (HCl) solution using weight loss analysis and electrochemical impedance spectroscopy (EIS). The effectiveness of coffee extract as a corrosion inhibitor was assessed through weight loss measurements under varying conditions, including the presence and absence of different inhibitor concentrations (0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.1%, 0.5%, and 1.0% v/v). The inhibition efficiency (IE) was examined at four temperatures: 20°C, room temperature, 60°C, and 100°C.

The results demonstrated that coffee extract serves as an effective corrosion inhibitor for mild steel in an HCl solution, achieving an efficiency exceeding 95%. As the inhibitor concentration increased, weight loss in mild steel samples decreased, leading to a higher IE at room temperature and 60°C. The enhanced inhibitor concentration facilitated the formation of a protective layer on the mild steel surface. However, this protective layer weakened as the solution temperature increased, resulting in a decline in inhibition efficiency over prolonged immersion times, particularly from 1 hour to 7 hours at 100°C.

The coffee extract was further characterized using Fourier Transform Infrared Spectroscopy (FT-IR). The FT-IR analysis revealed the presence of compounds such as catechin, chlorogenic acid, caffeine, and tannins, which act as anti-corrosive agents. These compounds enhance the effectiveness of coffee extract as a corrosion inhibitor by forming a hydrophobic thin film through the adsorption process.

Keywords: Mild steel, inhibition efficiency, EIS, coffee extract, green inhibitor.

INTRODUCTION:

Metals such as aluminum, mild steel, copper, and carbon steel are widely utilized in engineering and construction industries due to their affordability, workability, and distinctive physical, chemical, and mechanical properties. These metals play a crucial role in various applications, including military equipment, structural construction, weapons manufacturing, power plants, mining, nuclear power facilities, petroleum industries, cooling water systems, and the automotive sector.

However, these metals tend to lose their resistance when exposed to corrosive fluids, leading to degradation in harsh environmental conditions. Pure metals and their alloys undergo electrochemical reactions with corrosive ions, resulting in the formation of stable compounds and subsequent weight loss of the metal (Narasimha Raghavendra, 2019).

This study focuses on evaluating the effectiveness of coffee extract as a potential corrosion inhibitor for mild steel. The primary objective is to examine its inhibitory action in an acidic medium using weight-loss measurements and electrochemical techniques while also characterizing its chemical composition through Fourier Transform Infrared Spectroscopy (FTIR).

MATERIALS AND METHODS:

The blended coffee powder packet (Net Wt.500g)was obtained directly from online store. Three mild steel strips of 7 foot were collected from metal store and cut the strips into 3cm to obtain rectangular size coupons.

PREPARATION OF COFFEE POWDER EXTRACT SOLUTION:

To prepare a 5% coffee extract, 5 grams of coffee powder was added to 100 mL of boiled distilled water. The solution was then left at room temperature for 24 hours to undergo the digestion process. Afterward, the extract was refluxed at 40°C for 2 hours. Finally, the refluxed coffee solution was filtered using Whitman filter paper.

PREPARATION OF MILD STEEL SPECIMEN:

Rectangular mild steel (MS) coupons were prepared by cutting mild steel strips into average dimensions of 30 × 20 × 1.5 mm. The specimens were then rubbed with silicon carbide abrasive paper of varying grades, ranging from 120 to 420 grits, to remove the oxide film. Afterward, they were polished, degreased with acetone, thoroughly cleaned, and dried before being used in the corrosion weight loss measurement experiment..

PREPARATIONOF ELECTROLYTE:

The analytical reagent grade of HCl was used for the current study. This acid was diluted with doubledistilledwatertoprepare0.1MHCl.Freshlyprepared0.1MHClsolutionwasusedforeach set of experiments.

WEIGHT LOSS METHOD:

This method is a non-electrochemical technique used to determine corrosion rates and inhibitor efficiency. It provides more reliable results compared to electrochemical techniques, as the experimental conditions closely mimic real-world scenarios.

For the weight loss measurement, polished and pre-weighed mild steel specimens with dimensions of 30 × 20 × 1.5 mm were immersed in 0.1M HCl solutions, both with and without varying concentrations of the inhibitor (coffee extract) at 0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.1%, 0.5%, and 1.0% for 1, 3, 5, and 7 hours at room temperature. The absence of the coffee extract solution served as the reference sample.

After the specified immersion periods (1, 3, 5, and 7 hours), the specimens were removed, washed with distilled water, completely dried, and their final weight was recorded using a digital balance. The experiment was also conducted at different temperatures (20°C, 60°C, and 100°C) to determine the optimal temperature at which the inhibitor performs most effectively.

The weight loss of the test specimens was calculated using Equation (1):

Weight loss=Wo−Wi\text{Weight loss} = W_o - W_iWeight loss=Wo−Wi

where WoW_oWo is the initial weight of the mild steel specimen (in grams) and WiW_iWi is the final weight of the mild steel specimen (in grams) after each specified time interval.

The inhibition efficiency (IE%) was determined using Equation (2):

Inhibition efficiency=R0−R1R0×100\text{Inhibition efficiency} = \frac{R_0 - R_1}{R_0} \times 100Inhibition efficiency=R0R0−R1×100

where IE% represents the inhibitor efficiency, and R0R_0R0 and R1R_1R1 (in grams) correspond to the weight loss of mild steel in the absence and presence of the inhibitor, respectively.

ELECTRO CHEMICAL IMPEDANCE SPECTROSCOPY (EIS):

Electrochemical Impedance Spectroscopy (EIS) is a widely recognized quantitative technique for the rapid assessment of the anti-corrosion effectiveness of protective coatings. In a short testing period, EIS measurements provide reliable data, enabling the prediction of the long-term performance of coatings. The outcome of EIS analysis represents the impedance of the electrochemical system as a function of frequency

SAMPLE CHARACTERIZATION:

Fourier Transform Infrared Spectroscopy (FT-IR) was used to characterize sample (coffee extract). It is used to determine the presence of certain functional group in a molecule of organic andinorganiccompoundsofasamplewhichisresponsibleforinhibitoryaction.Activefunctional groups play a crucial role in the effectiveness of organic corrosion inhibitors. These functional groups interact with the metalsurface and forma protective layer, preventing further corrosion.

For characterization of sample, 2 ml of sample extract (5% of coffee extract) was sent to CEBS, University of Mumbai.

RESULTS AND DISCUSSION:

The results were obtained at room temperature and indicate that weight loss decreases as the inhibitor concentration increases (0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.1%, 0.5%, and 1.0% v/v). Mild steel immersed in HCl without the inhibitor exhibited the highest weight loss, ranging from 0.034 g at the beginning to 0.048 g at the end of the 7-hour experiment. Additionally, inhibition efficiency improved with increasing inhibitor concentration. At the highest concentrations of 0.5% and 1% (v/v), complete inhibition (100%) was observed, with no detectable weight loss of the immersed metal coupon. This effect is likely due to the adsorption of extract constituents onto the mild steel surface, which becomes more pronounced as the inhibitor concentration increases.

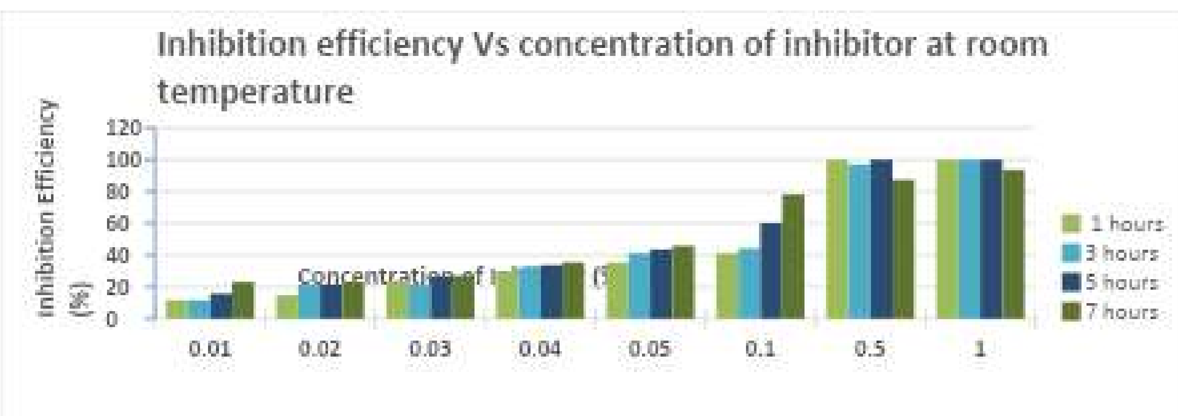

Figure1.1 Inhibition efficiency vs concentration of inhibitor at Room Temperature

Weight loss study at cold temperature(2°C):

The results of weight loss method were carried out at cold temperature. The result shows that as concentration of inhibitor increases weight loss of mild steel coupon decreases. The inhibitor shows maximum adsorption at concentration of 0.5% and 1% (v/v) at 1hours and 5 hours. The inhibition efficiency at various concentration decreases as the time increases from 1 hour to 7 hours. The variation in inhibition efficiency (IE) with the increase in inhibitor concentration at studiescoldtemperatureispresentedinFigure1.2.Therefore, inhibitor shows maximum effecting 1 hours of immersion time at higher concentration and decreased its efficiency as time increases.

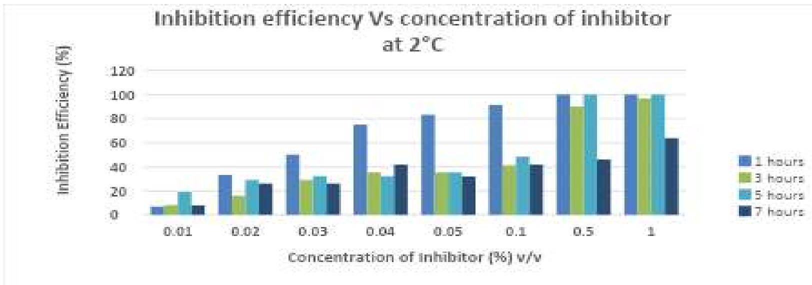

Figure1.2 Inhibitionefficiencyvsconcentrationofinhibitorat2 °C

Weightlossstudyat60°C:

The weight loss result obtained at studied temperature 60oC shows that as the concentration increases weight loss in metal coupon decreases and percentage efficiency increases from1 hr to 7 hr. The graph of percentages efficiency v/s concentration of inhibitor obtained is recorded in Figure1.3. The percentage efficiency at concentrationof0.5 and 1 are shows maximum inhibitor effect (100% efficiency). Thus, inhibitor works efficiently at 60°C at higher concentration with increase immerse time.

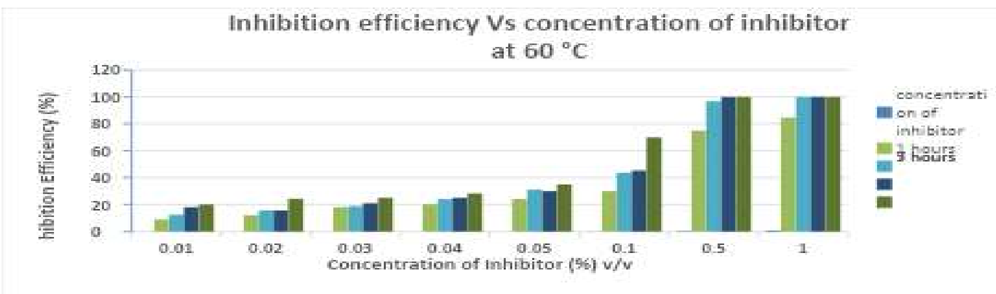

Figure1.3 Inhibition efficiency vs concentration of in hibitorat 60 °C

Weight loss study at 100°C

It shows that as the time increases percentage efficiency decreases at higher concentration. Inhibitor does not work efficiently at higher temperature (100°C).

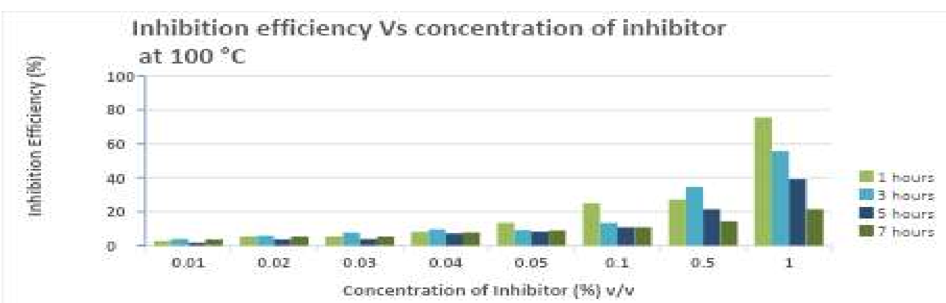

Figure1.4 Inhibition efficiency vs concentration of inhibitor at100°C

ELECTRO CHEMICAL IMPEDANCE SPECTROSCOPY(EIS):

The analysis was conducted to evaluate the effectiveness of corrosion inhibitors in protecting the surface of mild steel in acidic solutions. The tests involved studying the corrosion process of mild steel samples in an acidic medium, both in the absence and presence of coffee extract as a corrosion inhibitor. The acidic solution used was 0.1M hydrochloric acid (HCl). The experiment was performed at room temperature, where electrodes were immersed in the corrosion inhibitor solution and in 0.1M HCl. After data collection, the results were compared with a blank sample (without a corrosion inhibitor).

Electrochemical impedance spectroscopy (EIS) measurements were then performed. A comparison of Figures 4.5 and 4.6 indicates that the blank sample exhibited a higher imaginary impedance value compared to the inhibited sample. As shown in Figure 1.5, electrochemical reactions occurred at a higher rate in coupons exposed to HCl alone than in those treated with the inhibitor, leading to an increased corrosion rate in the absence of the coffee extract.

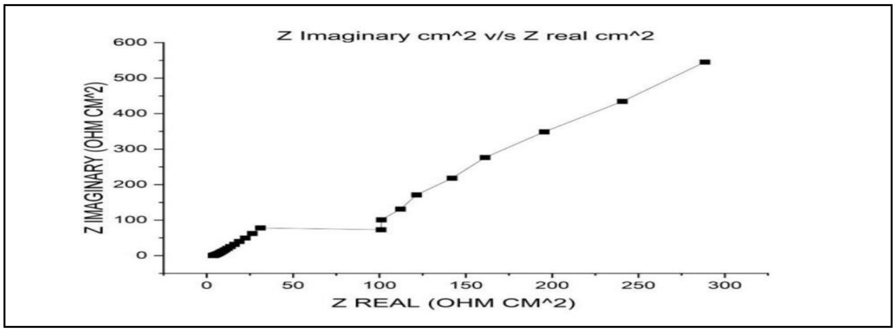

Figure:1.5 Plot Ny quist for mild steel using coffee extract as an electrolyte

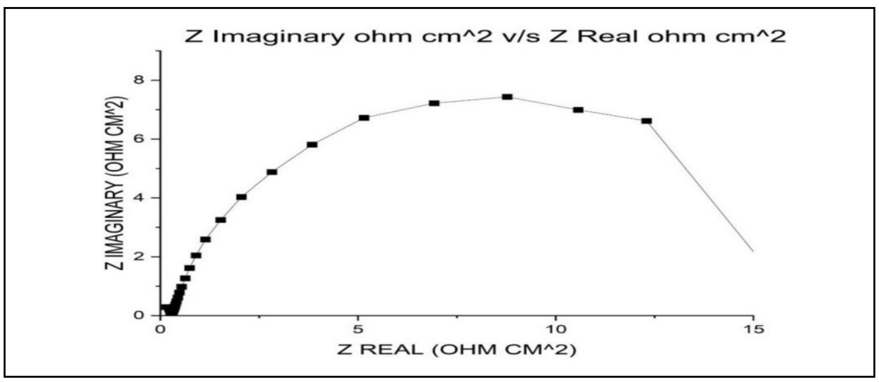

Figure:1.6. Plot SyQuest for mild steel using HCL as an electrolyte

CHARACTERIZATIONOFCOFFEEEXTRACTSOLUTION:

The coffee extract (inhibitor) solution was characterized by using FT-IR to determine the presence of certain functional group in a molecule of organic and inorganic compounds. Figure 1.7 shows the FT-IR spectrum peaks of the coffee extract solution. In this spectrum, the peak appeared at 3302 cm-1 corresponds to stretching mode of hydroxyl (O-H) and (N- H) amide group. While at peak 1635 cm-1 corresponds to the stretching mode of carbonyl group (C=O).

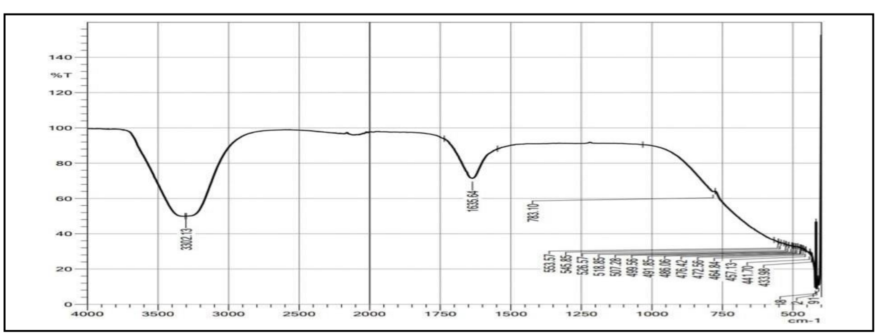

Figure1.7.FT-IR spectrum of coffee extracts solution.

CONCLUSION:

In the weight loss method, mild steel (MS) coupons were measured for weight loss at different temperatures with and without varying concentrations of the inhibitor (0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.1%, 0.5%, and 1.0% v/v). The weight loss was determined by measuring the metal coupons at different time intervals—1 hour, 3 hours, 5 hours, and 7 hours—after immersion in 0.1M HCl. Corrosion rate (CR) and inhibition efficiency (IE) were found to be highly dependent on temperature variations. The inhibition efficiency increased with higher inhibitor concentrations at all studied temperatures (2°C, room temperature, 60°C, and 100°C), which can be attributed to chemisorption, leading to the formation of a strong adsorbed layer on the metal surface. However, as the temperature increased from room temperature to 60°C and then to 100°C, the IE% decreased accordingly.

At room temperature and after 1 hour of immersion, the IE increased from 11.76% to 100% when the coffee extract concentration was raised from 0.01% to 0.5% in 0.1M HCl solution. Similarly, across all studied temperatures, a reduction in CR and an increase in IE confirmed the strong inhibitory properties of coffee extract molecules in an acidic environment. However, at the highest concentration of coffee extract (1%), the IE decreased from 100% at room temperature to 21.42% at 100°C. This decline in IE with rising temperature suggests that physisorption occurs due to desorption from the steel surface. Nonetheless, at the highest inhibitor concentrations (0.5% and 1%), maximum inhibition efficiency was observed at room temperature and 60°C. Based on these findings, the optimal temperature range for the effective performance of coffee extract as a corrosion inhibitor is from room temperature to 60°C.

A corrosion inhibitor is generally classified as effective if its inhibition efficiency exceeds 90%. Therefore, coffee extract demonstrated excellent performance as a corrosion inhibitor in 0.1M HCl solutions. The inhibition effect of the extract is attributed to the presence of chemical constituents that adsorb onto the mild steel surface. Coffee extract contains functional groups such as hydroxyl, amide, and carbonyl, as identified by infrared (IR) spectroscopy. These functional groups play a significant role in corrosion inhibition by interacting with the iron in steel, forming coordinate bonds that reduce steel dissolution and enhance corrosion protection at all tested temperatures.

This The findings from the weight loss method are consistent with those obtained from electrochemical measurements. Electrochemical impedance spectroscopy (EIS) results confirmed that coffee extract effectively reduced and slowed down the corrosion process of mild steel in hydrochloric acid. Data obtained using the potentiostat Autolab instrument and NOVA software demonstrated that at the highest inhibitor concentration (5%), a protective layer formed, preventing or significantly slowing corrosion. In contrast, the presence of HCl alone accelerated the corrosion process on the mild steel surface.

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