INVESTIGATION OF CORROSION INHIBITION EFFECT OF UNRIPE *MUSA SAPIENTUM* PEEL EXTRACT ON MILD STEEL IN HCL SOLUTION USING CORROSION STUDY KIT

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Abstract
Organic inhibitors, such as plant extracts are now essential as a suitable source for a variety of corrosion inhibitors that are also affordable, readily obtainable and environmentally friendly. This study describes the inhibition effect of unripe Musa sapientum (banana) peel extract at varying pH values of HCl solution in the corrosion of mild steel. The experimental work was conducted under ambient conditions. A corrosion study kit using weight loss corrosion monitoring technique was employed for the investigation. This equipment has a voltage supply designed to accelerate corrosion rate. The corrosion inhibition investigations were conducted using experimental setups consisting of HCl solutions with pH values of 2, 3, 4, 5, and 6. 5mls of unripe Musa sapientum extract was maintained in each setup. Each experimental setup has its corresponding control. The findings corroborated the concept that corrosion rates increase with increasing acidity of the medium (lowering pH). It was concluded that the Musa sapientum peel extract performed better in weakly acidic media (pH6, pH5 and pH4) compared to strongly acidic media (pH2 and pH3), and hence can be used as organic 'green' corrosion inhibitor which can be used in place of expensive toxic chemical inhibitors. The inhibition was attributed to the physical adsorption of the inhibitor on the surface of the mild steel test specimens. Unripe Musa sapientum extract in pH6 medium after 2 hours exposure time exhibited the highest inhibition efficiency of 66.67% on mild steel and can thus be proposed for usage in industrial and commercial processes under a moderately acidic environment.

Keywords: Corrosion, Corrosion Study Kit, Extract, Inhibitor, Mild Steel, *Musa sapientum*.

Introduction

Corrosion is the degradation of materials as a consequence of chemical reactions with their immediate environment (Fontana, 1986). The environment could be a liquid, gas, or a soil-liquid hybrid. Because these environments have their own conductivity for electron transmission, they are referred to as electrolytes (Perez, 2004). Mild steel is widely used in industry, particularly for structural purposes, although its susceptibility to corrosion in humid air and high dissolving rate in acidic environments are key barriers to its widespread use (Bilgic *et al*., 2001; Okuma and Onyekwere, 2022). Acids in solution are aggressive to mild steel structural components, and using inhibitors is one of the most effective techniques to prevent mild steels from corrosion (Eddy *et al.*, 2008; Ahanotu *et al.*, 2022). Inhibition is utilized internally with mild steel vessels and pipes as a cost-effective alternative to stainless steels as well as coatings on nonmetallic components (Ahmad, 2006; Anaele and Ipeghan, 2018).

Notwithstanding the excellent results using inorganic corrosion inhibitors, these compounds are not only prohibitively costly, but also hazardous and non-biodegradable, resulting in environmental concerns. As a result of these shortcomings, there is a quest for suitable eco-friendly organic inhibitors as substitutes (Patni *et al*., 2013; Shehnazdeep and Pradhan, 2022). Green corrosion inhibitors, known to be environmentally benign and derived from natural sources like as plant extracts, are experiencing an increasing rise in popularity (Avwiri *et al*., 2003; Baran *et al*., 2016). A number of studies have conducted a critical assessment of green corrosion inhibitors that are derived from plant extracts (Badawi and Fahim 2021; de Souza Morais *et al*., 2023). The inhibiting features of a plant extract are typically ascribed to the combination of phytochemicals present in it, which possess diverse functional groups capable of adsorption onto a metallic surface (Fazal *et al*., 2022; Zakeri *et al*., 2022). These phytochemicals can be categorized into several significant types, namely tannins, flavonoids, saponins, glycosides, alkaloids, phytosterols, steroids, phlobatannins, anthraquinones, phenolic compounds, amino acids, and triterpenes (Alrefaee *et al*., 2020; Salleh *et al*., 2021).

When *Musa sapientum* (Banana) peels are discarded, they become solid waste materials, which poses a concern on the environment, due to an inadequate system of solid waste management in Nigeria (Olafadehan and Salami, 2011).

These peels represent a form of organic waste, which comprises a significant proportion, approximately 62%, of the total solid waste produced in Lagos, Nigeria (Adogame, 2009). To address this issue, this study aims to explore the potential utilization of the extract derived from these peels as corrosion inhibitors in mild steel facilities mainly within the oil and gas industry. By doing so, it seeks to not only address the issue of waste management but also generate economic value from these waste materials.

Methodology

The materials utilized in this study encompass mild steel sheet, with its composition outlined in Table 1, Unripe *Musa sapientum* peels, Absolute HCl (Analar Grey with assay 35-5-37-5% W, W.CL, 1.175.1-185 g/20C weight per ml), Distilled water, Soxhlet apparatus and Corrosion study kit. The following methods or procedures were followed:

Preparation of Mild Steel Coupons

Mild steel sheet with chemical composition shown in Table 1 was cut in to test specimens or corrosion coupons with dimensions of 3cm × 2cm × 0.2cm with the aid of the metal cutting machine. A total of 60 samples were produced. A 0.3cm diameter hole was drilled in each cut specimen. The specimens were subsequently subjected to polishing using emery paper with several grit sizes, specifically p220, p400, p600, and p800. The process was aimed to expose the surface of the specimens for the purpose of corrosion monitoring. Subsequently, the specimens underwent a cleaning process utilizing ethanol. Afterwards, the specimens were placed in a desiccator with calcium chloride to ensure a moisture-free environment, so mitigating any potential contamination before commencing the corrosion experiment.

Table 1: Chemical composition of mild steel used

Constituent Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al
% Composition	0.008	<0.0001	0.271	0.0003	0.0092	0.011	0.026	0.0022	0.007
Constituent Element	Cu	Co	Ti	Nb	V	W	Pb	B	Sn
% Composition	0.027	<0.0001	<0.0001	0.0039	0.0014	<0.0001	0.0022	0.0008	0.0009
Constituent Element	Zn	As	Bi	Ca	Ce	Zr	La	Fe	
% Composition	0.0016	<0.0001	0.0011	0.0002	<0.0001	<0.0001	<0.0005	99.6	

Preparation of Unripe *Musa Sapientum* Peels

Two bunches of unripe *Musa sapientum* were bought from Ihio community in Ikeduru Local Government Area of Imo State, Nigeria. They were peeled, washed and subsequent air-drying at temperatures ranging from 30℃ to 40℃ for a duration of 25 days, in order to effectively eliminate moisture content. The dried *Musa sapientum* peels were then ground to near powder using an industrial scale grinder.

(a) *Musa sapientum* plant (b) Dried *Musa sapientum* peels (c) Ground *Musa sapientum* peels

Fig. 1 (a - c): Preparation of powdered unripe *Musa sapientum* peels for the extraction.

Extraction Process

The Soxhlet extraction method was employed to extract oil from the unripe peel of *Musa sapientum* obtained from the ground. The finely ground peel of *Musa sapientum* was placed within the primary chamber of the Soxhlet extractor, contained within a thimble constructed from dense filter paper. The distillation flask was thereafter filled with Petroleum Ether, followed by the placement of the Soxhlet extractor on its upper part. Subsequently, a condenser was affixed to the Soxhlet apparatus. The solvent was subjected to reflux by applying heat. As it ascends the distillation arm, the solvent vapour enters the chamber containing the powdered peels thimble. The solvent vapour then cools and drops back down into the chamber containing the powdered peels, owing to the condenser. For several hours, this cycle was permitted to repeat until the desired extract was achieved.

Corrosion Study Kit

Corrosion study kit allows studying of corrosion phenomenon and demonstrating how potentially corrosive situations may be recognized and avoided using a simple equipment consisting of a series of test cells. It was used to study the effect of pH on the rate of corrosion and chemical inhibition. The model of the corrosion study kit employed in this study was Armfield, IC136D-Corrosion-Code 998100. It was used with ten perforated plastic containers to ensure appropriate fit in the equipment in order to achieve the desired outcome. The equipment has a voltage supply which supplies voltage into the media, hence facilitating the corrosion rate. A voltage of 12volts was used for this study.

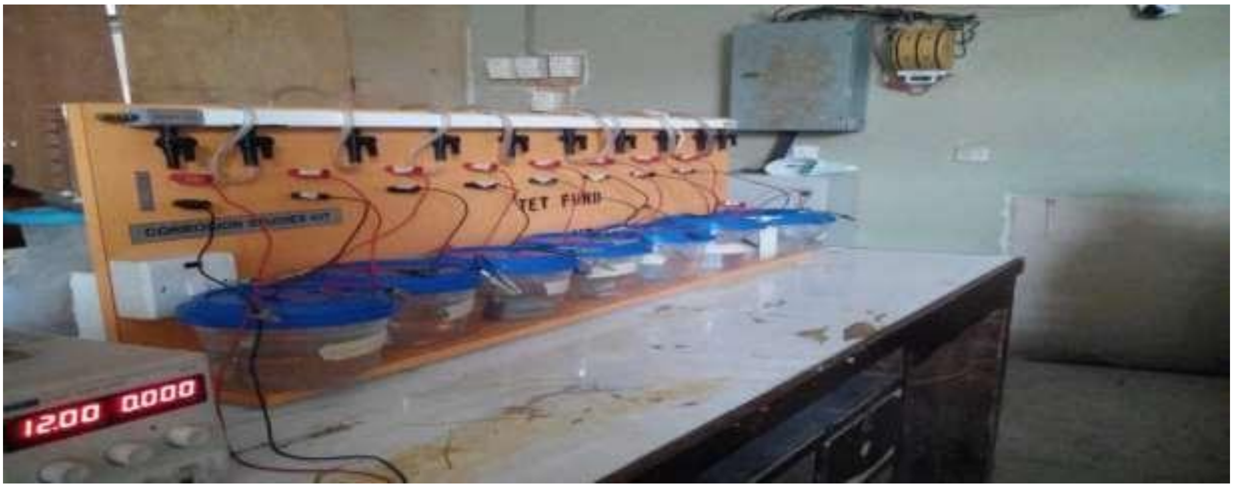

Fig. 2: Armfield Corrosion Study Kits

Preparation of Environment and Experimental Procedure

To prepare the study environment, 1litre of distilled water was put inside each of the ten plastic containers. Little drops of HCl were carefully dropped in to the containers and the pH was carefully determined using the pH meter after thorough stirring and stabilising of each medium. This was done for all the setups to achieve pH2, pH3, pH4, pH5 and pH6. In each of the five setups, 5mls of the extract (inhibitor) was injected, while the other five served as control setups. Two coupons were fully submerged with the corrosion kit wires in each bath, and covered appropriately to avoid interference from the atmosphere. Each setup was left for different periods of exposure times, ranging from 2, 4, 6, 8, and 10 hours. The digital weighing balance was employed to measure the weight of the coupons prior to and subsequent to each interval.

The corrosion rate (expressed in mm/yr) and the exposed surface area were determined using the following calculations:

- Corrosion rate (mm/yr.) = $\frac{KxW}{\rho xAxT}$ (1)

Where: W = Weight loss (mg)
ρ = Density of specimen (g/cm^3) = 7.9g/cm^3
A = Surface Area of specimen or coupon (cm^2) = 14.0471cm^2
T = Time of exposure (in hours)
K = 87.60

- Inhibitor efficiency (%) = $\frac{CR_u - CR_i}{CR_u}$ x 100 (2)

Where: CR_u = Corrosion rate of the uninhibited system
CR_i = Corrosion rate of the inhibited system

Results and discussion

Tables 2, 3, and 4 display the outcomes pertaining to weight loss, corrosion rate, and inhibition efficiency, correspondingly. These values where then graphically represented in Figures 3, 4 and 5 respectively.

Weight Loss

Table 2 and Figure 3 show the outcomes of the weight loss evaluations in various media. The results demonstrated that there was observable weight loss in each pH media, but the weight loss of the inhibited systems was invariably less than that of the uninhibited systems. The results of this study demonstrate that the extract derived from unripe *Musa sapientum* peel effectively inhibited the corrosion of mild steel specimens in an acidic media, as evidenced by the observed reduction in loss of weight. The mild steel coupon immersed in pH6 medium with 5mls extract had the lowest weight loss measurement. That is; 0.025, 0.026, 0.027, 0.029 and 0.028 mg respectively after exposure times of 2, 4, 6, 8 and 10 hours. Although, compared with the coupon immersed in pH6 uninhibited (control system), there was a notable increase in weight loss of 0.075, 0.077, 0.078, 0.08 and 0.081 mg respectively after exposure times of 2, 4, 6, 8 and 10 hours. At pH2 medium which is very acidic compared to the other media, the highest weight loss measurement was observed, with its uninhibited system having 0.286 mg weight loss after 10 hours. Hence corrosion was observed to have occurred the most in this medium owing to its high acidity.

Table 2: Weight loss in various media.

Time (hrs)	pH2		pH3		pH4		pH5		pH6	
	Un-inhibited	Inhibited	Un-inhibited	Inhibited	Un-inhibited	Inhibited	Un-inhibited	Inhibited	Un-inhibited	Inhibited
2	0.225	0.154	0.111	0.048	0.094	0.039	0.081	0.029	0.075	0.025
4	0.241	0.171	0.121	0.055	0.103	0.047	0.084	0.031	0.077	0.026
6	0.252	0.187	0.135	0.061	0.106	0.051	0.087	0.033	0.078	0.027

8	0.275	0.201	0.148	0.078	0.113	0.053	0.089	0.036	0.080	0.029
10	0.286	0.212	0.154	0.084	0.114	0.056	0.09	0.037	0.081	0.028

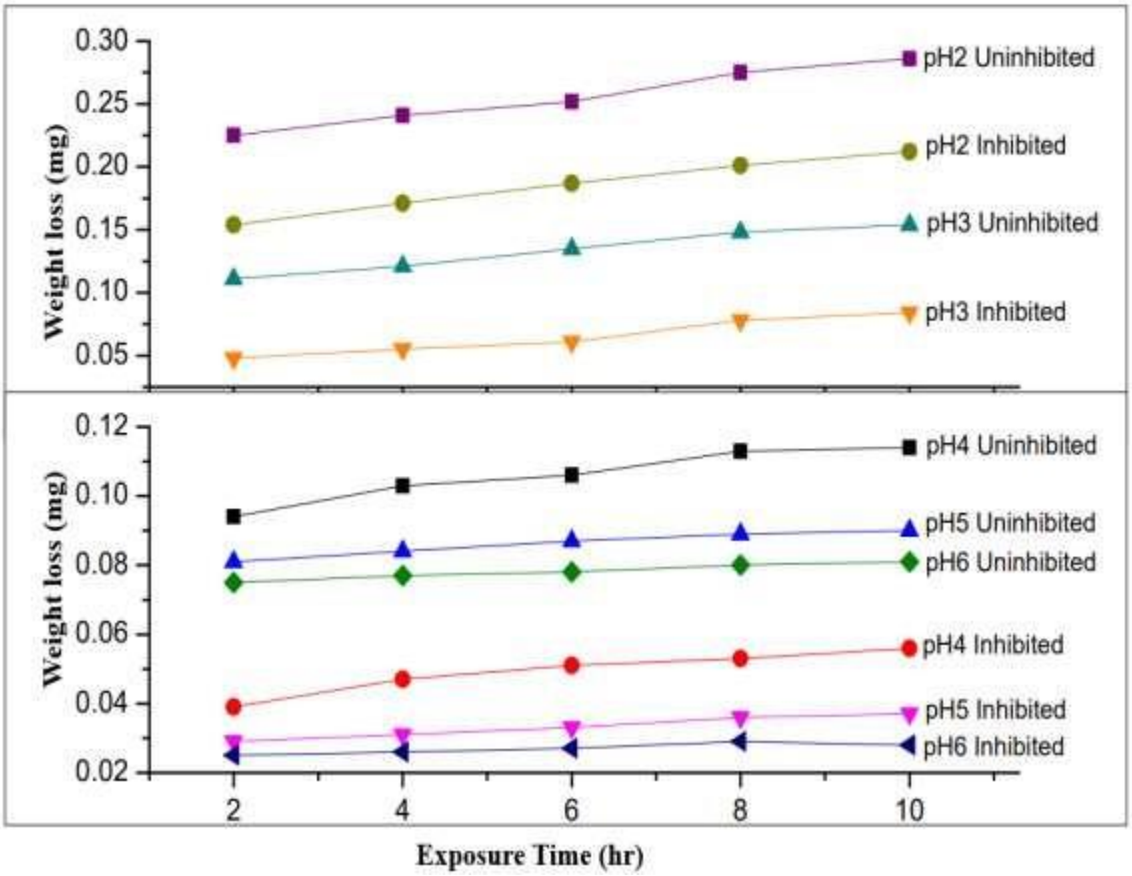

Fig. 3: Effect of Exposure Time on Weight Loss.

Corrosion Rate

The corrosion rates of the mild steel coupons in various pH media are as presented in Table 3 and Figure 4. The results obtained showed that the higher the acidity of the medium (lower the pH), the higher the corrosion rate. The lowest corrosion rates were observed in pH6 medium while pH2 had the highest corrosion rates. The specimen that was immersed in a solution with a pH of 6 for a duration of 2 hours had the most effective inhibitory action, as evidenced by the lowest corrosion rate of approximately 0.01 mm per year. The pH2 medium exhibited the least inhibitory effect, with a corrosion rate of 0.061 mm/yr, when immersed for a duration of 2 hours. The data shown in Figure 4 demonstrates that the application of *Musa sapientum* peel extracts resulted in a decrease in the corrosion rate observed on the mild steel coupon when exposed to varying pH levels of the HCl solution. The corrosion rates seen in the inhibited systems consistently exhibited lower values compared to the corrosion rates observed in the comparable uninhibited systems, across different pH media. The observed reduction in corrosion rate over time, as well as the inhibitory effect, can be ascribed to the phenomenon of physical adsorption of the inhibitor, specifically the extracts derived from *Musa sapientum* peel, onto the surface of the mild steel. The deposition of a film layer efficiently hinders the liberation of hydrogen ions and the dissolution of metal ions. In media containing inhibitors at pH 3 and pH 5, the corrosion rates exhibited constancy throughout the time frame of 6 hours to 8 hours. The observed phenomenon can be ascribed to the inhibitor's formation of a rather weak passive oxide film on the surface of the coupons. This film was unable to adequately impede the progression of corrosion within the given timeframe.

Table 3: Corrosion rate (mm/yr.) in various media.

Time (hrs)	pH2		pH3		pH4		pH5		pH6	
	Un-inhibited	Inhibited	Un-inhibited	Inhibited	Un-inhibited	Inhibited	Un-inhibited	Inhibited	Un-inhibited	Inhibited
2	0.089	0.061	0.044	0.019	0.037	0.015	0.032	0.011	0.03	0.010
4	0.048	0.034	0.024	0.011	0.020	0.009	0.017	0.006	0.015	0.005
6	0.033	0.025	0.018	0.008	0.014	0.007	0.011	0.004	0.010	0.004
8	0.027	0.020	0.015	0.008	0.011	0.005	0.009	0.004	0.008	0.003
10	0.023	0.017	0.012	0.007	0.009	0.004	0.007	0.003	0.006	0.002

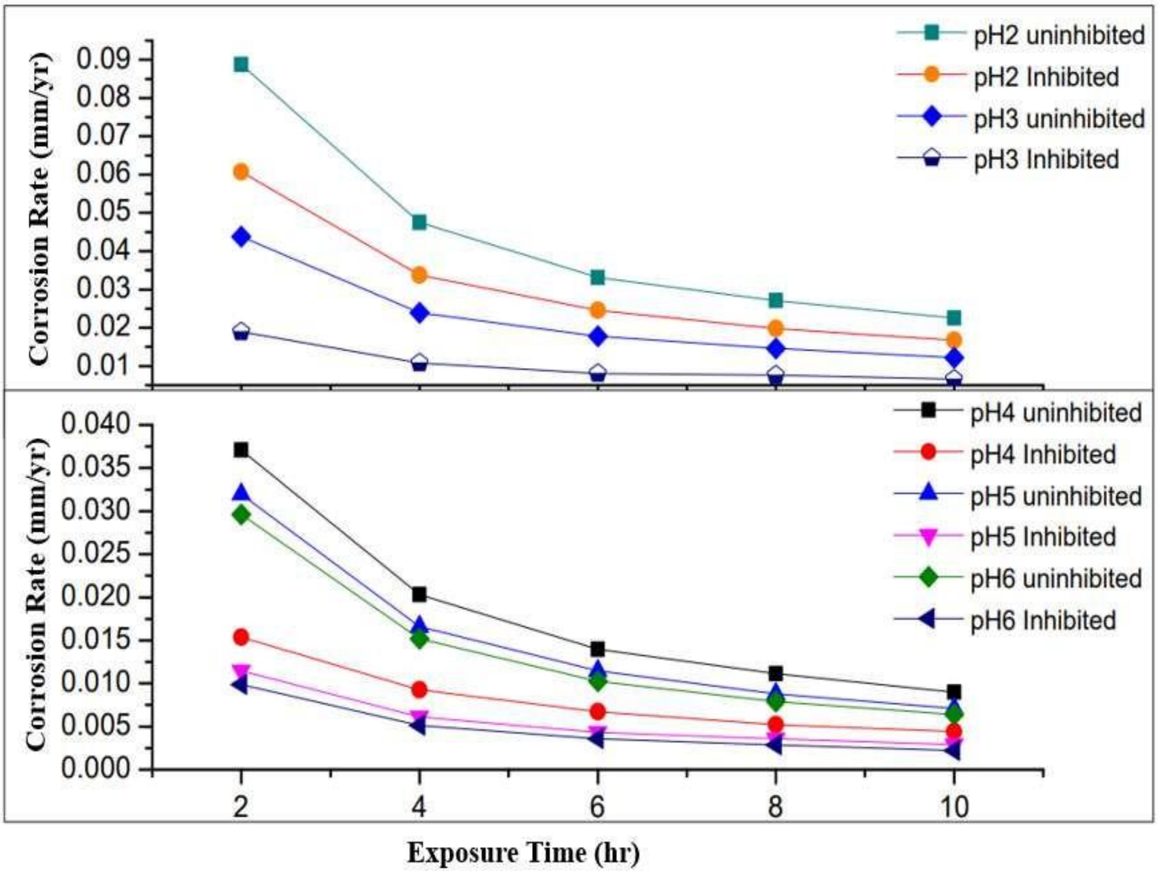

Fig. 4: Effect of Exposure Time on Corrosion Rate.

Inhibition Efficiency

Table 4 and Figure 5 present the inhibitory efficiency results acquired for different time intervals in various pH media. According to the data presented in Figure 5, it is evident that a pH of 6 exhibits the highest level of inhibitory efficacy at all times. After 2 hours, pH6 medium had the highest inhibition efficiency of 66.67%, which decreased with time to 66.23, 65.39, and 63.75% after 4, 6, and 8 hours, respectively, before marginally increasing to 65.43% after 10 hours. The lowest inhibitor efficiency was observed in pH2 medium after 6 hours. Figure 5 further shows that all the pH media had their best inhibitor efficiency after 2 hours, with 31.56, 56.757, 58.51, 64.198 and 66.67% for pH2, pH3, pH4, pH5 and pH6 respectively. The corrosion process was effectively inhibited through the facile adsorption of the extract onto the surface of the metal, thereby lowering or hindering metal dissolution; however, the adsorption became slightly weaker with time in all the pH media. It can be inferred that the extract performed better in weakly acidic media (pH6, pH5 and pH4) compared to strongly acidic media (pH2 and pH3).

Table 4: Inhibition efficiency (%) of the various pH media.

Time (hrs)	**pH2**	**pH3**	**pH4**	**pH5**	**pH6**
2	31.560	56.757	58.510	64.198	66.670
4	29.050	54.545	54.370	63.095	66.230
6	25.790	54.815	51.890	62.069	65.390
8	26.910	47.297	53.100	59.551	63.750
10	25.870	45.455	50.880	58.889	65.430

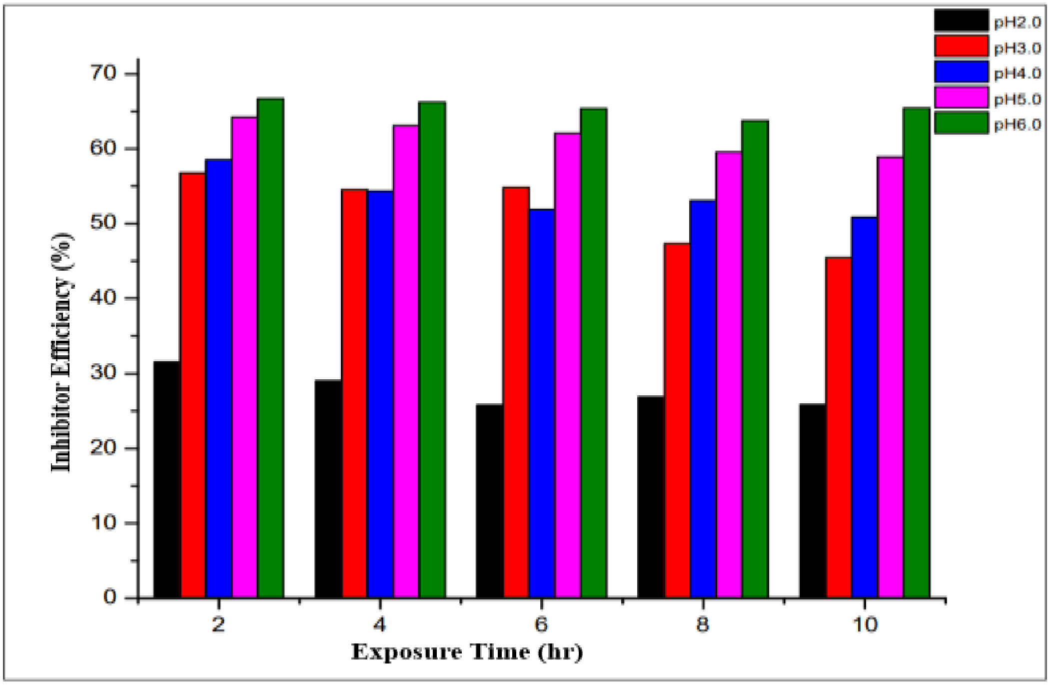

Fig. 5: Effect of Exposure Time on Inhibition Efficiency.

Conclusion

The utilization of unripe *Musa sapientum* peel extract as an organic inhibitor for the corrosion of mild steel in HCl acid media at different pH levels (pH2, pH3, pH4, pH5, and pH6) has been investigated. Based on the utilization of 5mls of unripe *Musa sapientum* peel extract, it can be inferred that the extract exhibited superior performance in weakly acidic media (pH 6, pH 5, and pH 4) when compared to strongly acidic media (pH 2 and pH 3). Following a 2-hour exposure period, it was observed that the pH6 medium exhibited the most significant inhibitory efficiency, reaching a value of 66.67%. The observed inhibition was ascribed to the phenomenon of physical adsorption, wherein the inhibitor molecules adhere to the outer layer of the mild steel test specimens. Therefore, unripe *Musa sapientum* peel extract will be both economically and environmentally advantageous as an organic inhibitor.

The results of this study revealed that the 5mls extract was not efficient for inhibiting mild steel corrosion in strongly acidic environments. Therefore, it is recommended to perform further investigations by augmenting the concentration of unripe *Musa sapientum* peel extract beyond 5mls in order to determine the optimal concentration needed to attain maximum inhibition efficiency in strongly acidic environments.

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