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Kalanchoe Pinnata Extract as a Green Corrosion Inhibitor for Mild Steel: Effect of Concentration and Temperature in Sulfuric Acid

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Abstract—*When it comes to green and low carbon development, the fast development of industry brings the problem of metal corrosion cost increasing protection methods for metal corrosion lead to great concern. The extracts from Kalanchoe Pinnata (KP) leaves, which were obtained through a simple process of maceration, were used as an inhibitor for iron corrosion. In 1N* H_2SO_4*. Their composition and anti corrosion properties were later studied and evaluated. The phytochemicals present in the extract form a protective adsorption in the anti corrosion quality intensifies with the increase in concentration , but reduces over a period of time as the temperature increases when the concentration of KP is* 10^{-5} *M the corrosion efficiency reached 73.77% after increasing the concentration the corrosion inhibition efficiency reached 88.65% at* 10^{-3} *M. The adsorption of KP onto the iron surface follows the Langmuir kind of adsorption model. The further studies will consist of Galvanostatic Polarisation, Potentiostatic Polarisation, Infrared Spectroscopy, Quantum Chemical Calculations, Temperature Kinetics, Scanning Electron Microscopy.*

Keywords: *Plant extract, Iron, Corrosion, Inhibitors.*

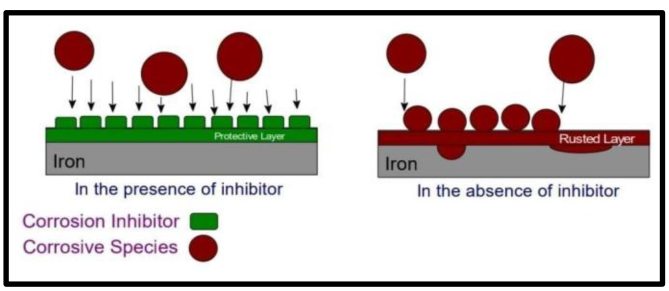


Fig. 1: The graphical representation of the working of an inhibitor on a piece of Iron.

INTRODUCTION

According to the IUPAC (International Union of Pure and Applied Chemistry). Corrosion is an environment dependent irreversible interaction between the material with its surroundings, resulting in dissolution of material. It is a spontaneous electrochemical process where refined metals naturally but through corrosion they revert to their original ore, making it an inevitable process of nature. The degradation of metallic structures poses a pernicious and prevalent challenge globally. Generally occurring through simultaneous anodic (oxidation) and cathodic (reduction) reactions at the interface of metal-environment. The metal has the tendency to react with natural agents such as saline water or air if it is not stopped by using some chemicals on it to prevent it from being oxidised means from being corroded. The metal degradation results in increased loss of production which arises from being contaminated and corroded instruments malfunctioning of industrial products through aqueous products. Due to leakage of contaminated material by corrosion remain untreated, it will cause equipment failure in near future.

The utilization of metals by humans can be seen since ancient times. The elevation of the usage of metals recorded with the onset of the industrial revolution and technological advancements. The society remains dependent on metallic materials from structural steel of bridges to aerospace components of aluminum alloys. The widespread use of the metallic products leads to safety and economic concerns [1-5].

Cause of Corrosion

The studies performed shows that the metallic materials tend to be reactive chemically with their strength totally depending on the extent to which they influence the reactivity and successive degradation of the materials. The various other factors that influence the materials are : 1) Metal Purity 2) Temperature 3) Air Humidity 4) Environment of Surface film 5) Electrolyte's Ph [2-4]

Metal Purity: The rate of the corrosion generally rises with increasing impurities because of these impurities small-small electrochemical cells formed which allow a non-cathodic part for corrosion, for example iron lead and zinc.

Environment of Surface Film : In an aerated environment metals formed meta oxide as a thin film on its surface. This is called a "specific volume ratio". The oxidation state is inversely proportional to specific volume ratio; for example Co, W and Ni shows 2.0, 3.6 and 1.6 as the oxidation rate.

Temperature: The rate of corrosion elevates by higher temperatures; for every 100°C the rate doubles. The copper and aluminium experiments at 50°C and 25°C on pH values 4.8, 7 and 8.2 found out that the rate of corrosion decreases, elevating pH; increases with higher temperatures. The exponential curve shows the temperature related increase of corroding structures; but many cases showed a more complex relation because the temperature change can also alter other factors and effects.

Air Humidity : Humidity of air has a crucial role in depicting corrosion rate. As far as corrosion rates are concerned, it increases sharply at the point of relative humidity and because of that the oxide film possesses to absorb moisture, resulting in creation of another electrochemical corrosion. Also , the atmosphere's moisture will give water to electrolyte from setting electrochemical cells.

Electrolyte's pH: The level of pH is an important determinant for the rate of corrosion with lower values of pH are associated with greater corrosion rate. The environments with pH less than 7 are acidic environments which show higher corrosive nature as compared to basic or neutral mediums. Noble gases such as platinum and gold the rate of corrosion is low showing very less dependence on solution's pH. Other metals like zinc; lead and aluminium possess significant elevation in the rate of corrosion in both basic and acidic media. Thus, explaining the solubility of these oxides of metals in both alkaline and acidic surroundings [2-4].

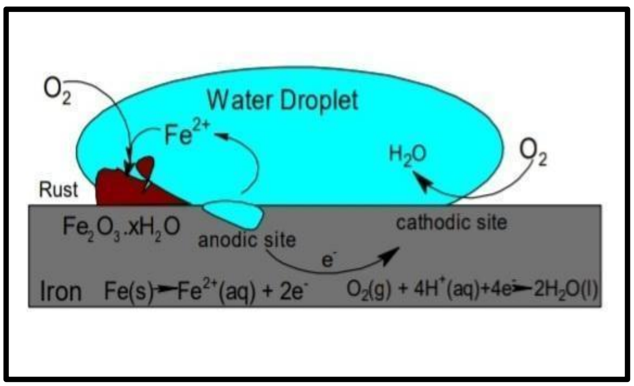


Fig. 2: Picture depicting the process of corrosion on a piece of metal.

Corrosion leading to economical loss:

The threat of corrosion being an universal phenomenon causes direct as well as indirect losses. In the world every nation pays off a hidden tax of corrosion. In India, alone pays off 4-5% of GDP because of corrosion with approx. 6% of the annual output spent on the replacement of the materials that are corroded; 20% of iron production is wasted every year. The threat of corrosion varies from loss of life to time loss in production. Therefore, the main motive of interest in the studies of corrosion arises from economic considerations. The need to sustain aging structures while designing for more than thousands years of lifespans.

The need for the corrosion rate can be seen through history. The Ohio, USA; Silver Bridge Collapse in 1967 due to stress corrosion cracking which claimed 46 lives. The Bhopal, India accident in 1984 occurred due to corroded pipelines resulting in 3000 lives. In 2000 New Mexico, USA resulting in 12 killed and 3 vehicles damaged.

Hence, the study of corrosion has been very essential to the world's decreasing resources. Other than that, there are other significant areas that the corrosion covers again. There have been seen and recorded various accidents or incidents that have cost the money and life of the people. Health hazards have been reported where the contaminated water supply has been seen in the year 2025 in India. The unpredictable critical parts that cause the loss of the nation cannot be ignored. Thus, in order to maintain all the stated problems essential solutions need to be developed [4-6].

Types of corrosion

Corrosion can be classified as follows [5-10]

- Uniform Corrosion
- Crevice Corrosion
- Stress Corrosion
- Pitting Corrosion
- Galvanic Corrosion
- Fretting Corrosion
- Filiform Corrosion
- Inter Granular Corrosion
- Localised Corrosion
- Waterline Corrosion

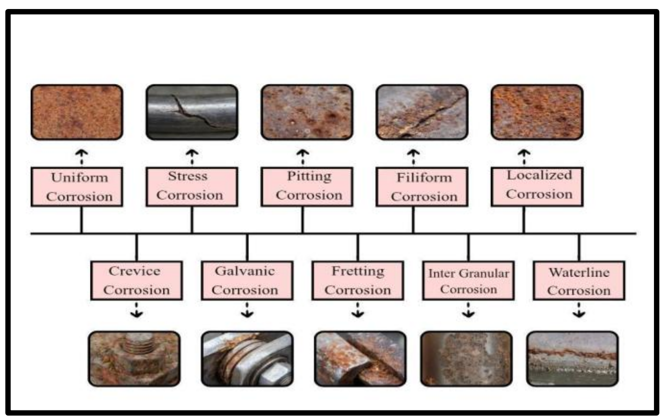


Fig. 3: Representation of various types of corrosion

Uniform corrosion. This is known as general corrosion; the type of corrosion by which the destructed metal surface is perished evenly or uniformly. The corrosion proceeds with the same rate throughout the destructed metal. Oxygen is one main cause in this corrosion. Commonly products cast iron and steel show this dry corrosion. The results are seen when the materials are left exposed to the moist atmosphere, resulting in a similar appearance to rust.

Crevice Corrosion: This is the localised attack that takes place on a metal surface. It occurs in confined spaces that are known as crevices. These spaces have restricted fluid circulation; such as washers, gaskets etc. This takes place due to oxygen depletion in between the gaps. This leads to an acidic environment which may result in the destruction of protective layers.

Stress Corrosion Cracking (SCC): SCC is a type of corrosion that leaves behind deep cracks in the surface. This happens due to a highly corrosive environment with tensile stress on the surface.

Pitting Corrosion: The type of corrosion which makes small pits (holes) within the metal surfaces. It is a localised form of corrosion.

Galvanic Corrosion: The corrosion in which one metal gets corroded when it is in contact with another different metal that too in the presence of electrolyte. Sometimes, it is also known as bimetallic corrosion.

Fretting Corrosion: This corrosion occurs at the surface of two metal surfaces in contact which leads to the removal of the protective films [9].

Filiform Corrosion: The special type of corrosion looks like a worm under surface film. Generally seen in high humidity, majorly on materials of aluminum, steel and magnesium [10].

Inter Granular Corrosion: The corrosion mainly occurring at the edges or boundaries neglecting the central area of the surface. This sometimes also refers to as Inter Granular Attack which disturbs the materials exterior rapidly than the interior. From the studies the prime cause for such corrosion is sensitization.

Localised Corrosion: The corrosion opposite to that of Inter Granular Attack where the surface is attacked unevenly mainly at the core leaving the boundaries intact. This occurs rapidly causing deep penetrations resulting in structural failures.

Waterline Corrosion: The type of corrosion that occurs in partially filled tanks and ships. The submerged metallic surface gets affected by the waterline in contact where the submerged metallic surface with less oxygen molecules acts as an anode whereas area above the waterline acting as cathode.

The metallic materials needs to be protected from being corroded. Those preventive methods can include a) Coatings b) Cathodic Protection c) Anodic Protection d) Corrosion Inhibitors [11-16].

Coatings

The traditional way to protect the metallic surface is the use of protective coatings. These coatings are generally made up of a mixture of polymers, ceramics and even metal alloys. Protective coatings help by physically restricting the surface to come in contact with the surroundings containing corrosion factors. This method has been observed useful not only in normal air exposure, but also with the intensive chemical environment.

The numerous applications of this coatings includes use of polyurethane coating on automobiles making when scratch resistance and protecting from ultraviolet rays, thermal spray coates on industrial equipments to protect them from chemical stored, coatings of zinc, rich primers on bridges to protect from the corrosive environment.

Cathodic Protection

Cathodic protection is a simple yet useful technique for the prevention of metallic surfaces. In this technique the metal that needs protection is forced to be the cathode of an electrochemical cell. Cathodic protection may be fulfilled by two ways:

- Sacrificial anode cathodic protection: In this, the metal that needs protection is connected with a less noble metal that acts as anode. The studies show that magnesium, zinc and aluminium commonly used for the metal acting anode with time they get corroded , and are sacrificial anode. These are advised to be located nearer to area of protection because of their low driving voltage.
- Impressed current cathodic protection: In this protection, it uses a power source for preventing metal from being corroded. This external power source is regulated by a DC power supply known as a control panel. This works by sending electric current to the surface of the metal , which spreads through special anodes. The anodes are not easily dissolvable rather they help by causing various other chemical reactions at the surface.

The main aim in seawater is the production of chlorine gas by breaking down of chlorine ions:

$2Cl^- \rightarrow Cl_2 + 2e^-$

The main aim in the low salt water is the production of oxygen and acid by breaking down of water:

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

Anodic Protection

This method for protection carefully creates an oxidised layer of protection on the surface. This oxide film helps in protecting the metal from being corroded. Such a method protects metal in their passive condition and is known as anodic protection. A little current is required to maintain the formed passive layer.

Industrially, it has been used in storing sulphuric acid in containers, in fertilizer industry to withstand the high temperatures upto 95°C containing ammonia and ammonium nitrates.

Corrosion Inhibitors

The method of prevention using inhibitors is quite useful and interesting. As we know, the word inhibit comes from a latin word ‘inhibere’ which means to check. The chemical which gradually slows the corrosion rate, by forming thin molecule film onto metallic surface by adsorption.

The effectiveness of inhibitors depends on certain factors; those can be:

- Efficient Solubility
- Long carbon chain length
- Size of the molecule
- The conjugated bonding
- Number of bulky groups attached
- Heteroatoms present or not
- Bonding strength to metal substrate

The run for the effective inhibitor lies in the properties itself. The aim is to form a layer of barrier by adsorbing on the surface. This layer will reduce dissolution of metal and will help in preventing the direct contact from corrosive medium. Hence, the desirable inhibitor needs to be selected through knowledge and practical applications.

Aims and Objectives of the Present Investigation

The aim of the present study is:

1. To find efficient corrosion inhibitor
2. To determine its effects practically
3. To make it budget and environment friendly

In order to achieve better results all the factors like humidity, temperature, pH of corrosion have been kept constant as far as possible throughout the experiments.

The objective of the present investigation has been to study mechanism of adsorption of Kalanchoe Pinnata on mild steel surface in 1N Sulphuric acid by:

1. Weight Loss Analysis of the mild steel specimen.
2. Galvanostatic Polarisation at different temperatures; 298K, 308K and 318K.
3. Potentiostatic polarization at room temperature for denoting the passivation behavior of mild steel.
4. Infrared spectroscopic studies for information about the mechanism of adsorption process.
5. The studies of scanning electron microscopy to get morphological details of the metal in the absence and presence of the inhibitor.
6. Calculation of effective activation , energy and absorption heat of the corrosion processes in the presence and absence of the inhibitors.
7. The study of ultraviolet visible spectroscopy to get details of the complex organic structure.

The study aims to collect data on various aspects of adsorption behavior of Kalanchoe Pinnata on mild steel specimens in 1N Sulphuric acid.

Methodology Used:

These are non toxic eco-friendly biodegradable substances. The main focus of the study is to develop an inhibitor that is not expensive and efficient. The primary principle it works on is surface adsorption. A thin layer of inhibitor molecules is accumulated on it for protecting the surface from corrosion.

Preparation and Extraction of Components:

1. Preparation of the Plant Extract: A simple cold extraction process was chosen for the extraction. The plant extract was prepared by the process of maceration. The fresh leaves of Kalanchoe Pinnata (KP) were taken and washed. After that these were thoroughly dried and grinded into powder. This powdered compound was dipped in the ethanol as solvent and left undisturbed for four days. In four days the phytochemicals of the plant leaf burst out of the soften cell wall and dissolve with the solvent. The mixture was then filtered and centrifuged in the centrifugation machine. The required plant extract is obtained containing alkaloids, tannins and other complex structures in it.

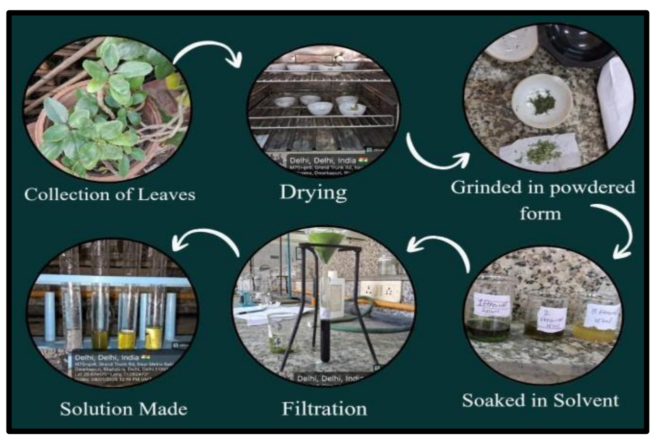


Fig. 4: Depicting the preparation of the plant extract from Kalanchoe P(KP) leaves.

2. Preparation of the Metal Specimen: Pieces of mild steel were purchased from the market. The pieces in our experimental work were of dimensions 1.0 cm × 1.0 cm × 2.0 cm. These coupons were cut in these dimensions with

care. The coupons were then smoothened by using emery paper for further studies. These specimens were degreased with the help of acetone. Then these were cleansed with double distilled water and left in the desiccator for 24 hours, in order to avoid any moisture. Now, these coupons are ready to be used in our experimental studies.

Weight Loss Analysis

The first study performed is to determine the weight loss of the coupon. The specimens were introduced in the acidic environment with presence of plant extract and without the presence of extract to determine the difference between the initial and the final weight after a reasonable time interval [21-22].

IE% = [Wu - Wi/ Wu] × 100%

where;

IE% = Inhibition efficiency

Wi = Weight loss of mild steel in inhibited solution

Wu = Weight loss of mild steel in blank solution

Ultraviolet Visible Study of the plant extract

This technique is performed to find out the absorption of the complex structure present in plant extracts. These complex structures are present in the form of phytochemicals, which contain alkaloids, tannins, saponins and more. This was performed on MS UV Plus double beam spectrophotometer.

Quantum Chemical Calculations

Afterwards these calculations are performed which will help in finding more suitable corrosion inhibitors. This approach will be based on the correlation between the set of independent variables and the dependent variables for example , dipole moments , HOMO and LUMO energies. The methods like HMO method, MNDO method, PM3, Austin Model 1 and EHT are used for the calculations. The order of inhibition can be observed later for mild steel in sulphuric acid medium.

Scanning electron microscopy (SEM)

SEM, the technique which helps by scanning the sample with a focused electron beam, giving high resolution images about its topography, microstructure and composition. The scanning electron microscopy of the initial acid coupon and the final inhibited coupon will be done.

Electrochemical measurements

In this inhibition of corrosion, the electrochemical measurements will be performed using potentiostatic and galvanostatic techniques.

Potentiostatic polarisation study involves maintaining a constant voltage onto the sample over some time. The results will then provide the study of the passivation behaviour, the pitting susceptibility and the quantitative data of the rate of corrosion.

Galvanostatic polarisation gives the studies of mild steel samples in acidic solutions at 298K 308K 318K and 328K. These studies will let us know whether the inhibitor will be cathodic, anodic, or mixed type inhibitor.

Temperature Kinetics will give the details of corrosion data by analysing the values of surface coverage and adsorption isotherms.

Results and Discussions

The results of the findings give the idea of being an effective inhibitor for the sample.The study start with the weight loss analysis of all the plants : Kalanchoe Pinnata (KP).

Observation Table

1) Reading of 1N H_2SO_4 solution at different concentrations.

Table 1: Weight Loss Method

Sets	Plant Extracts used as inhibitor	Concentrations (M)	Initial weight of coupon (g)	Final weight of coupon (g)
1	KP	10^{-3}	2.8097	2.7768
		10^{-5}	2.9087	2.8326
		10^{-7}	2.8057	2.7075

Formula Used:

IE% = [Wu - Wi / Wu] × 100%

where;

IE% = Inhibition efficiency

Wi = Weight loss of mild steel in inhibited solution

Wu = Weight loss of mild steel in blank solution

Results Obtained:

For all the sets the maximum efficiency was obtained at 10^{-3} M concentrations, that were as the following:

Set 1: KP

IE% = 0.2902 - 0.0329 / 0.2902 × 100

= 88.66 %

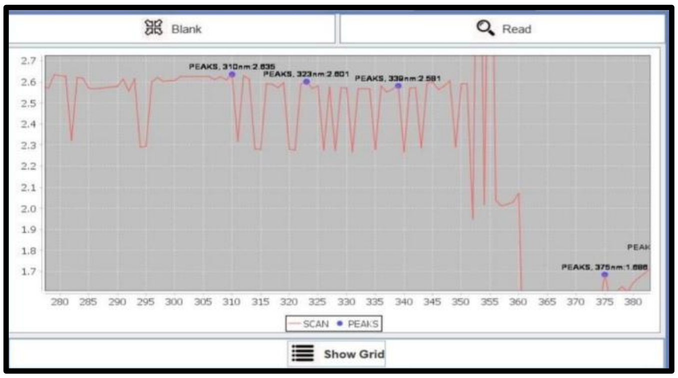
This method gave us the idea about the accuracy of our studies. The analysis clearly showed that increasing concentrations increases the inhibition efficiency. The graph for the same can be seen.

2. Ultraviolet Visible Spectroscopy

This study was proceeded in order to obtain the peaks of phytochemicals in the extract's sample. It is a technique to identify and fetch details of the various bioactive components generally referred to as phytochemicals which is based on the ability for the absorption of light. This helps us by providing complex chemical analysis of the plant extracts; this will also help in monitoring the efficiency and quality of extraction.

The flavonoids gave peaks of 300 -350nm.

The peaks from 200 - 300 nm showing alkaloids.



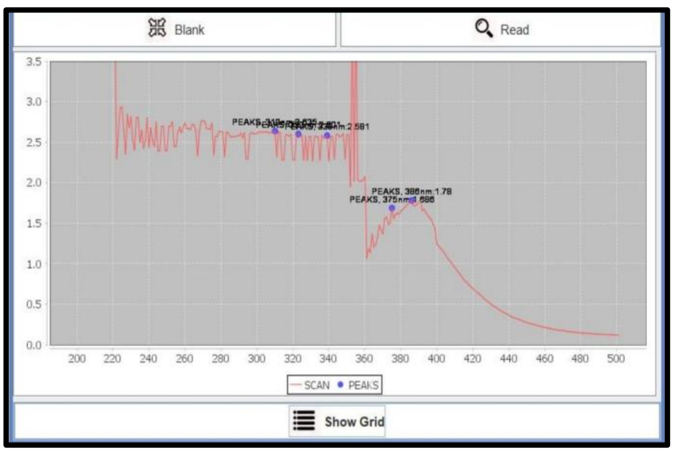


Fig. 5 & 6: The obtained UV Spectrums

After the Ultraviolet Spectroscopy Analysis the individual tests for active phytochemicals were carried out for their verification. The tests that were performed and supported the readings are listed below:

Test for Alkaloids

1) Mayer's Test

- In a test tube of 1ml of plant extract; a few mayer's reagent drops were added.
- Then this mixture was shaken with care.

A yellow or white colored precipitate will be observed. This confirms the presence of alkaloids.

2) Wanger's Test

- 0.5 plant extract was taken in a test tube.
- It was dissolved in 1 ml of 1%(v/v) HCl.
- Then 3 drops of Wanger's reagent was added to the solution.

The reddish colour confirms that the basic alkaloids were present.

Test for Saponins

1) Foam Test

- In a test tube 1 gm of extract of dried plant was taken. To this, 2.5 ml of distilled water was added.
- This obtained mixture was shaken completely for 40 seconds.

The obtained foam after a span of 30 minutes confirms the presence of saponins.

Test for Flavonoids

1) Alkaline reagent test

- In a test tube 2 ml of the plant extract was taken.
- To this solution of plant extract a 3 drops of NaOH was added.
- To this mixture 5.2 ml was added of dilute HCl.

Onto the addition of dilute HCl the yellow color disappears. Hence, confirming the presence of flavonoids.

2) Shinoda's test/ Mg-hydrochloride reduction test

- In a test tube 2 ml of plant extract was taken.
- To this 12 drops of dil. HCl was added.
- Then a magnesium ribbon was introduced to this mixture.
- This will get dissolved when a few drops of HCl was poured carefully in the solution.

The obtained color of deep-red and orange confirms the presence of flavonoids.

Test for Terpenoids

1) Salkowski's Test

- In a test tube 5 ml of plant extract was taken.
- Then this was dissolved in 2 ml of chloroform with 2 drops of con. sulfuric acid.
- The mixture was shaken and left still for some time.

The reddish brown interface confirms terpenoids present in the extract.

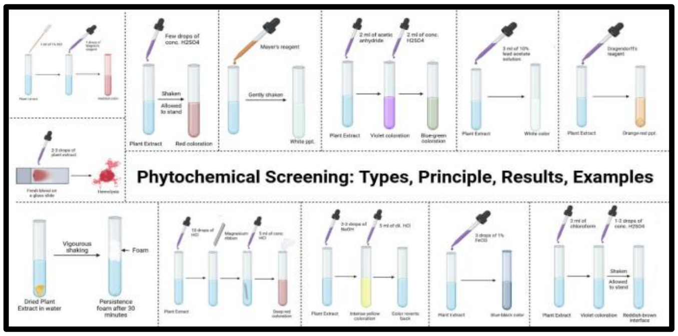


Fig. 7: The image is from Phytochemical Screening: Types, Principle, Results, Examples; May 28, 2025 by Rashal Shakya [25-27].

3. Galvanostatic Polarisation

The method for determining the effectiveness of corrosion inhibitors. It can be seen as effective in different environments like vapor phases and neutral mediums. The working is based on the separation of anodic and cathodic processes. The metal dissolution occurs on the anodic region and the evolution of hydrogen can be seen on the cathodic region. The inhibitor's effectiveness is a comparison of current density and potential of the system with and without the inhibitor. The experimenter controls the current and measures the electrode potential which helps in plotting of Tafel Curves. At OCP, the cathodic and anodic current densities are equal to one another and are known as exchange current densities.

The equation used for the current density flowing and electrode potential is the Butler-Volmer Equation :

$i = i_a + i_c$

$i = K_a C_m \exp[(1-\alpha) zFE / RT] - K_C C_S \exp[-\alpha zFE / RT]$

Where,

i_a = anodic current density

i_c = cathodic current density

K_a = heterogeneous rate constant of anodic process

K_c = heterogeneous rate constant of cathodic process

C_m = concentration of oxidant

C_S = concentration of reductant

α = transfer coefficient

z = number of electrons transferred in reaction

F = faraday's constant

E = electrode potential

R = universal gas constant

T = temperature

Table 2: Galvanostatic Polarisation Studies

Temp. (K)	Conc. (mol^{-1})	-E_{Corr} (mv)	b_c (mv/dec)	I_{Corr} mA/cm^2	I%
298	10^{-3}	450	170	0.29	88%
	10^{-5}	474	120	1.6	59%
	10^{-7}	472	100	2.3	42%
	H_2SO_4	466	140	4.4	-
308	10^{-3}	485	190	0.68	84%
	10^{-5}	521	95	1.9	56%
	10^{-7}	516	75	2.5	53%
	H_2SO_4	463	50	5.2	-
318	10^{-3}	504	230	2.3	61%
	10^{-5}	516	50	5.1	42%
	10^{-7}	486	40	6.6	19%
	H_2SO_4	452	35	8.8	-

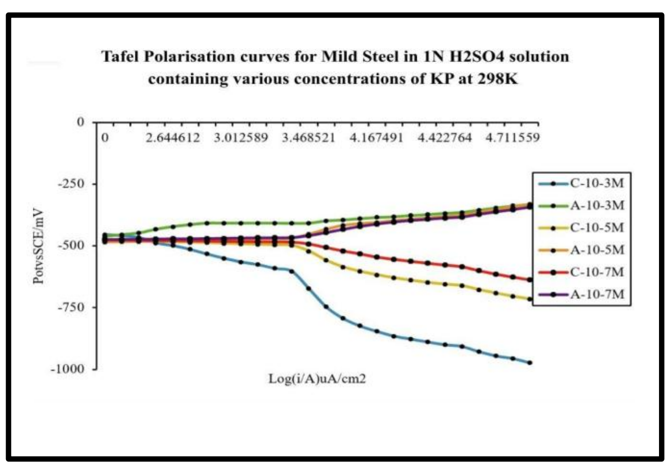


Fig. 8: Tafel Polarisation Curve at 298 K

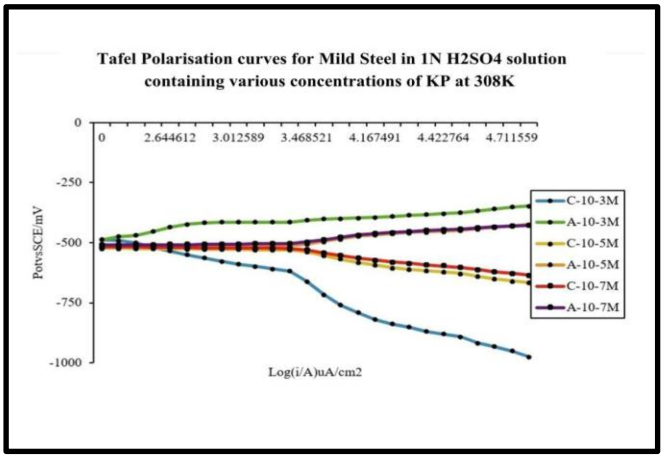


Fig. 9: Tafel Polarisation Curve of Mild Steel at 308 K

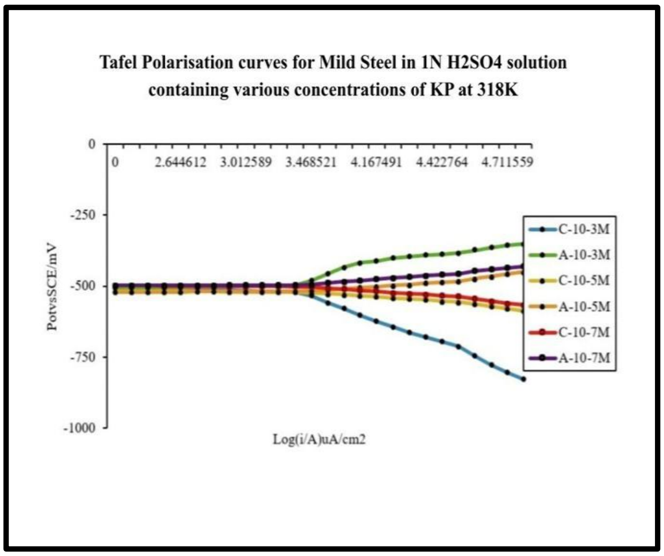


Fig. 10: Tafel Polarisation Curve of Mild Steel at 318 K

Interpretation of the Graphs:

The graphs show the cathodic and anodic studies of mild steel at three temperatures in 1N sulfuric acid medium with KP as inhibitor.

- The drop in the inhibitor's efficiency with heat at 298 K from 91% to 49% at 10^{-3} M due to this can be classified as a first class inhibitor.
- KP has not produced any shift of OCP in any direction indicating it is a mixed type inhibitor which affects the both cathodic and anodic processes to an equal extent.
- Tafel slope concludes that the change in the reduction current is not just due to adsorption but involves some change in the reaction mechanism.

4. Thermodynamic and Adsorption Studies

In the presence of acid aerated systems the corrosion of mild steel specimens will increase with rising temperature.

The temperature's effect of uninhibited and inhibited solutions of metal corrosion in acid medium has been studied by many. The rate of corrosion and adsorption kinetics can be calculated. The Arrhenius equation is used to calculate the activation energy at which the corrosion reaction will occur in the presence of the inhibitor. The Langmuir's adsorption isotherm is the basis of heat of adsorption. The inhibitors that will not follow Langmuir's adsorption, might follow other types of isotherms like

1. Temkin Isotherm
2. Frumkin Isotherm
3. Freundlich Isotherm

In the present work the behavior has been studied using Langmuir's adsorption isotherm.

Table 3: Thermodynamic and adsorption studies

Temperature (K)	Concentration (M)	I%
298	10^{-3}	88
	10^{-5}	67
	10^{-7}	53
	H_2SO_4	-
308	10^{-3}	83
	10^{-5}	67
	10^{-7}	58
	H_2SO_4	-
318	10^{-3}	77
	10^{-5}	40
	10^{-7}	37
	H_2SO_4	-
328	10^{-3}	63
	10^{-5}	51
	10^{-7}	24
	H_2SO_4	-

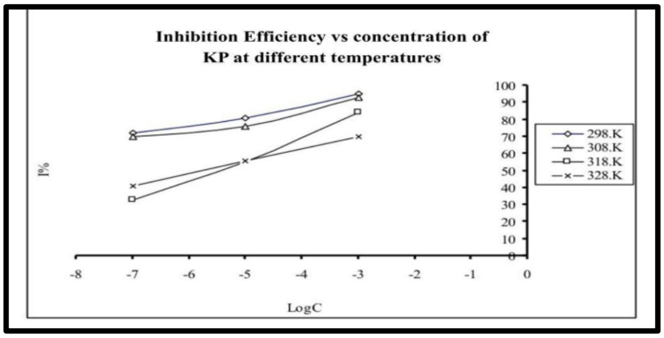


Fig. 11: The inhibition efficiency vs concentration at different temperature.

5. Study of Surface Morphology

- The advanced spectroscopic methods are able to provide information about the surface quantitatively. These include organic functional groups,oxidation states and material distribution on the surface.
- The present analysis of work was carried out using scanning electron microscopy. This provided the surface analysis of mild steel specimens when exposed to uninhibited and inhibited environments.
- The clear understanding of adsorption nature, corrosion extent and inhibition extent is seen.

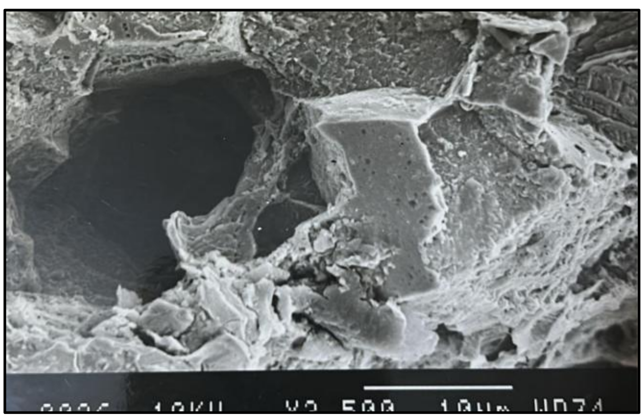


Fig. 12: SEM representation of 1N H_2SO_4

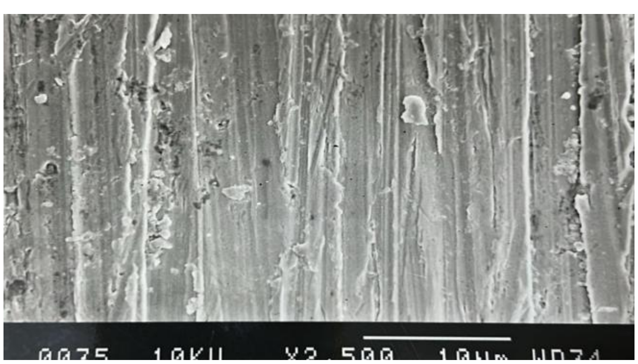


Fig. 13: SEM representation of KP inhibitor in 10^{-3} M concentration.

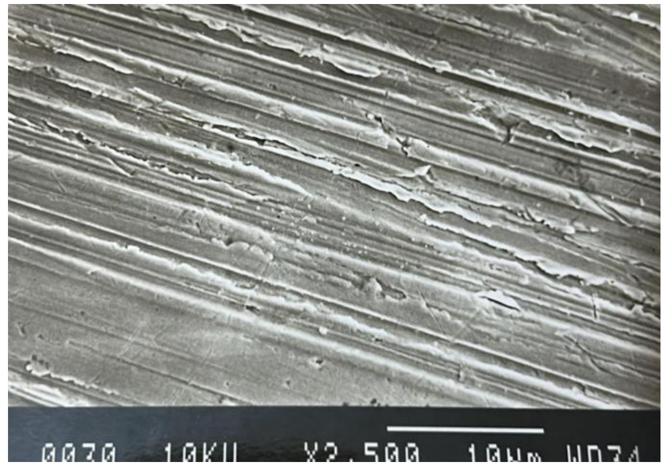


Fig. 14: SEM representation of KP inhibitor in 10^{-5} M concentration.

Observations: Scanning Electron Micrographs

- The metallic surface is free from any cracks and pits.
- On the corroded metal , the flakes of oxides and metal hydroxides can be observed.
- The surface of metal is covered with KP at 10^{-3} M of it providing a high degree of prevention.
- The surface of metal is showing some small cracks at 10^{-5} M KP.
- KP is an effective inhibitor at higher concentrations.

CONCLUSIONS

The cost effective systematic study of eco-friendly corrosion inhibitors for mild steel in 1N of H_2SO_4 at different concentrations from 10^{-3} to 10^{-7} (M) draws out the following conclusions.

- The inhibition efficiency of KP increases as the concentration of inhibitors increases.
- The Ultraviolet Visible Spectroscopy confirms the presence of complex structures of the plant extract. These complex structures are present in the form of alkaloids, tannins, flavonoids and saponins.
- SEM investigations confirm that the presence of protective film helps in reducing the effect of corrosion by absorbing the green inhibitor onto the surface of metal.
- It can be concluded that Kalanchoe Pinnata Leaves (KP) shows a great potential as an inhibitor for the use in industrial applications as a mixed type corrosion inhibitor.

FUTURE SCOPE

- The nano-carriers development that will encapsulate the inhibitors and allow self healing effect; in which the release of inhibitors will take place only when in need like the coating scratched off or any changes in the pH observed.

- The study of DFT and MD can be performed for the effectiveness of molecules before any lab tests.
- The study of tafel polarisation will be performed later.
- The combination of the plant extracts with drugs can be applied in future for better results with longer shelf lives.

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