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Experimental and theoretical studies of *Ficus religiosa* as green corrosion inhibitor for mild steel in 0.5 M H_2SO_4 solution

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ABSTRACT

Corrosion inhibition analysis and adsorption behaviour of *Ficus religiosa* fruits extract for mild steel in 0.5 M H_2SO_4 solution has been inquired utilizing scanning electron microscopy (SEM), atomic force microscopy (AFM), gravimetric measurements, electrochemical impendence spectroscopy (EIS), potentiodynamic polarization techniques, Ultraviolet-visible spectroscopy (UV–vis.), Fourier-transform infrared spectroscopy (FT-IR) and quantum chemical calculations. Electrochemical investigation and gravimetric estimations say that the fruits extract of *Ficus religiosa* shows the most extreme inhibition efficiency of 92.26% at 500 mg/L. The appearance of Myricetin, Serotonin and Campesterol as major phytochemical constituents in the extract of *Ficus religiosa,* decrease the corrosion rate of mild steel in acidic media. The adsorption of this extract obeys the Langmuir adsorption isotherm. Due to the presence of heteroatoms and aromatic rings in the major components of *Ficus religiosa*, it can serve as an effective corrosion inhibitor for mild steel corrosion in 0.5 M H_2SO_4.

1. Introduction

Most widely used alloy in the industrial process, fabrication and construction is mild steel due to its masterly mechanical competency, easy availability and the most important its low production cost [1]. Acids attack on the steel surface leads to corrosion problems. Corrosion can be controlled by using inhibitors [2]. It is very useful in the pickling process of metals where scale and dust remove but not create corrosion. But most of the synthetic inhibitors are expensive, toxic and hazardous to the environment [3,4]. This has prompted researchers to find out some non-toxic, eco-friendly, biodegradable, cheap and effective green inhibitors [5]. Plant extracts have required inhibiting properties such as they contain various organic compounds with heteroatoms like nitrogen, oxygen and conjugated bonds [6–9]. The organic molecules used as inhibitors are adsorbed on the surface of alloy through these heteroatoms and their conjugated system. This adsorption is either physical, by electrostatic interaction (physisorption) or chemical through covalent bond formation (chemisorption). The importance of the mechanism of corrosion inhibition, surface analysis and its relation to electronic and anatomical properties of the inhibitor molecule has also attracted attention to quantum chemical calculation [10–16]. Green corrosion inhibitors do not contains any heavy metals or other toxic compounds. Plant extract or green corrosion inhibitors have the potential to replace synthetic organic and inorganic inhibitors. The mechanism of action of green corrosion inhibitors depends on the structure of the active ingredient and thus many researchers have to date postulated many theories to explain this phenomenon. Many researchers already reported different plants as green corrosion inhibitor for acidic medium with good inhibition efficiency, such as: *Salvia officinalis* shows 96% inhibition efficiency at 2500 mg/L [17], *Osmanthus fragan* shows 94% inhibition efficiency at 340 mg/L [18], *Musa paradisica* shows 90% inhibition efficiency at 300 mg/L [19], *Achyranthes aspera* shows 90% inhibition efficiency at 500 mg/L [20], *Jasminum nudiflorum* shows 92% inhibition efficiency at 1000 mg/L [21], *Withania somnifera* shows 91% inhibition efficiency at 300 mg/L [22], *Dendrocalamus brandisii* shows 90% inhibition efficiency at 1000 mg/L [23], *Cuscuta reflexa* 95% inhibition efficiency at 500 mg/L [24], *Phyllanthus amarus* shows 81% inhibition efficiency at 4000 mg/L [25], Black radish shows 92% inhibition efficiency at 1000 mg/L [26], *Ginkgo* shows 80% inhibition efficiency at 100 mg/L [27], *Kola nitida* shows 78% inhibition efficiency at 1200 mg/L [28], Radish fruits show 79% inhibition efficiency at 100,000 mg/L [29], *Murraya koenigii* shows 96% inhibition efficiency at 600 mg/L [30], Bamboo leaf shows 89% inhibition efficiency at 200 mg/L [31] and *Butea monosperma* shows 98% inhibition efficiency at 500 mg/L [32].

Ficus religiosa is a large semi-evergreen tree belongs from *Moraceae* family and known as Bodhi tree, Ashwattha tree and Peepal tree. This tree generally achieves up to 30 m (98 ft) tall with a trunk diameter of

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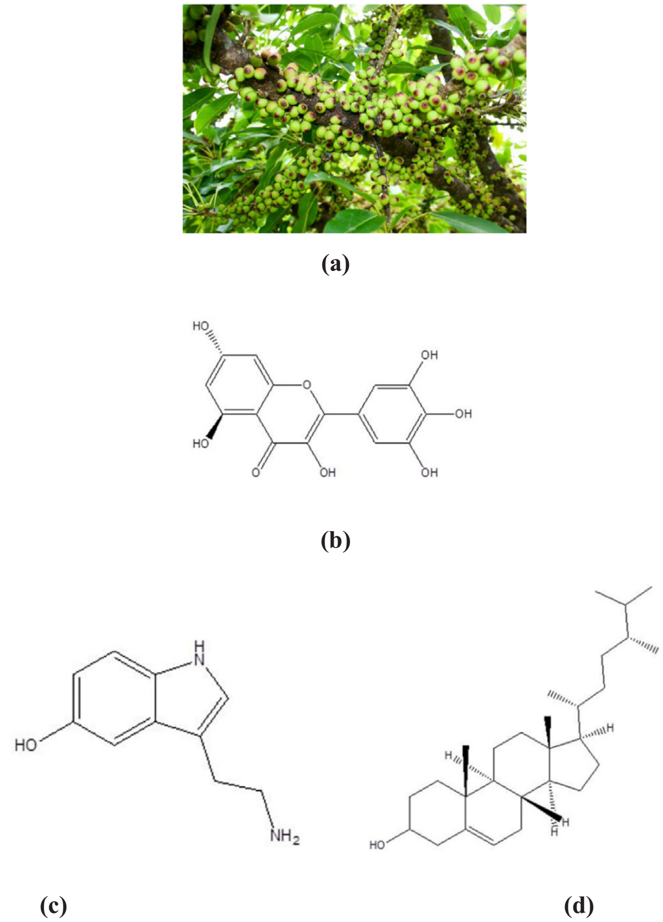

Fig. 1. **(a)** Picture of *Ficus religosa* fruits and its major chemical constituents **(b)** Myricetin, **(c)** Serotonin and **(d)** Campesterol.

up to 3 m (9.8 ft). It is commonly found in Asian countries like India, Shri Lanka, Pakistan, etc. and very easily available in the market. *Ficus religiosa* contains phenolic compounds like Myricetin, Serotonin and Campesterol [33,34]. Fig. 1 shows the picture of *Ficus religiosa* fruits and its major phytochemical constituents.

The present study is aimed to extract the *Ficus religiosa* fruits and investigate the corrosion resistance as a corrosion inhibitor of mild steel in 0.5 M H_2SO_4 based on gravimetric measurements, electrochemical impedance spectroscopy, potentiodynamic polarization measurement. In addition, the effects of structural parameters of inhibitors on inhibition efficiency their adsorption mechanism on the metal surface and correlate the experimental data with the quantum chemical parameters have been studied.

2. Experimental

2.1. Preparation of the working electrode

Mild steel rod (1 cm diameter) used in this study has a nominal (wt %) composition of Fe = 98.22%, Mn = 0.43%, P = 0.12%, Cu = 0.43%, C = 0.08%, Ni = 0.27% and Cr = 0.45%. The mild steel was incised and sectioned with Clarke power hacksaw and ESM 700 excel shaping machine to give mild steel specimens with an average length of 1 cm to use as the test specimens for gravimetric measurements and for electrochemical studies the same steel specimens were soldered to coated Cu-wires for electrical connections and after that mounted over epoxy resin with a laid open zone of 1 cm^2. Before any measurements, different grades of emery papers 100, 320, 600, 800, 1000 and 1200 were used to abrade the surface of the working electrode mechanically. After that, the mild steel specimens were rinsed with distilled water and acetone and finally dried in warm air flow.

2.2. Preparation of inhibitor and electrolytes

The raw product of *Ficus religiosa* was purchased from the market and it was validated by Dr. Arbeen Ahmad Bhatt under the accession number HERB/BOT/LPU-460 in the Department of Biotechnology Lovely Professional University Punjab, India. First, the fruits of *Ficus religiosa* were cleaned with distilled water to take out fiery remains of mud, dried the fruits for 48–72 h in the thermostat at 60 °C, grind and converted into powder form. Then the 100 gm of powdered *Ficus religiosa* was refluxed with ethanol at 75 °C for 24 h. The refluxed results were filtered, and the pH of the aqueous solution was found to be 9. The filtered solution was evaporated to 100 ml of dark brown reside and then dried in a vacuum drying oven at 60 °C for 48 h. At the point of dark brown colour deposited (around 5 g gummy material) was procured after complete drying and saved in a vacuum desiccator. The sulphuric acid was diluted to 0.5 M H_2SO_4 as the corrosive medium. The test solution with different concentrations of *Ficus religiosa* fruits extract (100, 200, 300, 400 and 500 mg/L) were obtained by diluting the extract with 0.5 M H_2SO_4. The corrosive solution (0.5 M H_2SO_4) was prepared from the reagent grade, 98% H_2SO_4 (Sigma Aldrich) and distilled water. The solution of the inhibitor in 0.5 M H_2SO_4 was prepared with various concentrations (100–500 mg/L). The greatest solvency of *Ficus religiosa* extract in 0.5 M H_2SO_4 was observed up to 500 mg/L.

2.3. Gravimetric measurements

For Gravimetric measurement estimations of the mild steel specimen was set up as ASTM G 31–72 [35]. Gravimetric measurements were done for 24 h at 298 K, 308 K and 318 K. 0.5 M H_2SO_4 acid blank solution and containing 100, 200, 300, 400 and 500 mg/L of *Ficus religiosa* fruits extract were prepared then the pre-weighted metal specimens were immersed in the text solution. Following drenching period, the metal specimens were excluded, deliberately rinsed with acetone, dried under nitrogen flow afterwards weighted to Shimadzu BL-220H/D455006313 electronic balance. The temperature of the experiments was kept up by keeping the beakers in the PPI Fini X48 water circulated thermostat (± 0. 5 K exactness). In this study, the average values of three replicates are reported.

2.4. Electrochemical measurements

CH Instrument Electrochemical Workstation was used to carry out electrochemical measurements. The cell system, an easy three-electrode, contains the mild steel electrode, a platinum electrode, and a saturated calomel electrode (SCE) as the working electrode, the counter electrode and the reference electrode respectively. For electrochemical measurements, the specimens were embedded in epoxy resin leaving a working area of 1 cm^2. At the beginning of the tests, the working electrode was immersed in the test solution for 1 h to get a stabilized open circuit potential (OCP). Electrochemical impedance spectroscopy (EIS) was scanned from the frequency of 100 kHz to 0.01 Hz with a signal amplitude perturbation of 5 mV at OCP. Respecting to OCP at the scan rate of 1 mV/s, potentiodynamic polarization curves were recorded with a scan of ± 250 mV vs. SCE. Reliable values were achieved by repeating all electrochemical measurements three times.

2.5. UV–visible spectroscopy

With the help of a Shimadzu UV-1800 UV–Visible absorption spectrophotometer, the Ultraviolet-visible (UV–vis.) spectra of *Ficus religiosa* in 0.5 M H_2SO_4 were recorded. The spectra were taken out in two different situations i.e. the acidic solution of inhibitor in which the