Review on assessment of corrosion of mild steel in alkaline environment by using plant extract

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Abstract. Many industries face corrosion caused by the alkaline medium. There are various techniques to minimize the corrosion such as anodic protection, cathodic protection, coatings and green corrosion inhibitor. To minimize the effect of corrosion in an alkaline medium, green technology i.e. green corrosion inhibitor has been widely used. Natural plant-based extract is used as green corrosion inhibitor to mitigate the problem of corrosion. It is naturally occurring, non-expensive, safe and ecologically acceptable. The plant origin extract contains tannins, alkaloids, organic, amino acids which are main functional groups in mitigating the corrosion. The present review paper summarizes the various plant-based green corrosion inhibitor used for minimizing the corrosion of mild steel in an alkaline medium. Also, the plausible mechanism for the inhibition of corrosion in alkaline medium is explained comprehensively.

1. Introduction

1.1 Corrosion

Mild steel is used in manufacturing industries and in construction sites. It includes handling of acid, alkali and salt solution. Mild steel (MS) contains 0.05% to 0.25% by weight of carbon hence known as low carbon steel. MS is very cheap, ductile, machinable and weldable. Mild steel is used in oil and petrochemical industry, fertilizer industry etc., MS is used as construction material in heat exchangers, making storage tanks, pipelines etc. Due to the aggressive corrosion behaviour, structure of metal, chemical constituent’s and composition gets damaged [1]. Some of the chemicals used in industries are Na₂CO₃, KOH, NaOH, NaCl, NH₄Cl and Ca (OH)₂. When the metal gets exposed to those chemicals, the deterioration of metal takes place. Metal’s corrosion control has practical, economic, ecological importance. Aggressive corrosion action in alkaline medium has high impact on industrial processing cost as well as on product [2]. Corrosion is a naturally occurring process which is monitored mainly in industries because it has great influence on the metallic structure. Corrosion causes financial implications in terms of product losses, renovation, replacement and environmental pollution. Leakage of products due to corrosion is one of the major losses in industry. If the corrosion contaminated product is left untreated then industry faces the failure of equipment [3]. In alkaline medium, passivation layer is formed on the surface of steel and protects the surface [4]. It has been evidenced that; in alkaline environment the film formation is explained based on double-layer model [5]. However, in the presence of chloride ions, passivation gets weakened, which leads to corrosion at higher rate [6]. There are various techniques to minimise the corrosion such as anodic protection, cathodic protection, coatings and green corrosion inhibitor [7].
1.2 **Green corrosion inhibitor**

Among all the method green corrosion inhibitor is green technology which is based on the usage of plants and biodegradable in nature, eco-friendly technology [8]. Corrosion rate of metals can be significantly reduced if green corrosion inhibitors are used and protect the metal against corrosion. Corrosion inhibitors are materials which are added in minor concentration to reduce the corrosion rate. Effectiveness of inhibitor relies on the absorption rate on metal surface and prevents the metallic surface from corrosion. Absorption on the metallic surface depends on the structure of the inhibitor’s molecules and charge of metal surface [9]. In many industries, inhibitors are used in various system / unit such as cooling systems, water processing unit, refinery units, pipelines, chemicals, oil and gas production units, boilers, paints, pigments and lubricants[10]. Literatures suggest that the corrosion inhibition is due to the adsorption of inhibitor molecules, such as N,O, S, double bonds, triple bonds or aromatic rings, on the metal surface and forming a stronger bond. Compounds have π-bonds show good inhibitive properties; also π-orbital provides the electrons for the surface interaction [11].

The techniques used to investigate the practicality of an inhibitor are weight loss study (WLS), electrochemical impedance spectroscopy (EIS), potentiodynamic polarization study (PPS), open circuit potential (OCP). In addition, Fourier-transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM) are used to characterize the corroded metal surface. From weight loss study (WLS), inhibition efficiency and surface coverage can be calculated to test the inhibitor effectiveness. EIS is used to understand the fundamental mechanism of corrosion inhibition in the metal.

The main purpose of this review article is to summarize the usage of non-hazardous; plant based green inhibitor to protect the mild steel from alkaline environment. Corrosion in steel rebar is the best example of usage of green corrosion inhibitor in an alkaline environment. Corrosion in steel rebar causes damages in concrete structure, when this rebar come in contact with water, salt (NaCl), carbon dioxide (CO₂) [12].

Corrosion of rebar damages concretes as well as it reduces the concrete strength. Particularly corrosion forms on rebar are galvanic, pitting and uniform corrosion. So, to provide lifelong service, some integrated approaches are taken to protect steel rebar from corrosion. There are various protection methods to protect the steel rebar from corrosion. To avoid environmental issue, green corrosion inhibitors have become favourable solution. Green corrosion inhibitors are not hazardous to environments, compatible with any type of concretes and eco-friendly as well as cost effective. Green corrosion inhibitor is applying and mixed in concrete is found more beneficial than any method [13].

This review analyses type of metal, inhibitor source, inhibition efficiency, corrosion rate (CR) and mechanism of inhibition. Table1 summarizes the various green corrosion inhibitor (GCI) effects on mild steel in presence of alkaline medium with the important findings reported in the literature. Several researchers have been done many researches in the acidic medium but much fewer work reports on the alkaline side due to the complexity in the inhibition.

**Table 1.** List of various plant extract as green corrosion inhibitors (GCI) of various metals in an alkaline medium.

| Sr. No. | Inhibitor                      | Metal | Medium          | Methodology  | Result                                      | Reference |
|---------|--------------------------------|-------|-----------------|--------------|---------------------------------------------|-----------|
| 1       | *Nigella Sativa* (Black cumin), *Coriandrum Sativum* | MS    | 3% NaCl         | • WLS        | • Mixed-type inhibition                     | [14]      |
|   | Plant Name                  | Environment | Solution(s)                      | Method(s)                           | Results                                                                                       | Reference |
|---|----------------------------|-------------|----------------------------------|-------------------------------------|------------------------------------------------------------------------------------------------|-----------|
| 2 | Thymus vulgar (thyme)       | MS          | NaCl                             | WLS, AIS, PPS                       | Maximum inhibition efficiency (IE) as 80.49%  
Temkin's adsorption isotherm  
Mixed type inhibition  
IE rises with inhibitor concentration (IC) | [15]      |
| 3 | Mix of Henna (Mehndi)/Zeolite powder | MS          | 1M NaOH                          | WLS, AIS, TS, SEM                   | Langmuir adsorption isotherm  
IE rises with IC  
Maximum IE as 95.97% at 30°C  
CR changes with respect to temperature and IC | [16]      |
| 4 | Amaranthus cordatus (velvet flower) | MS          | 0.5 M NaCl and 1 M NaCl          | WLS                                 | IE rises with rise in IC  
CR declined with IC. | [17]      |
| 5 | Pterocarpus soyauxii Taub (African Coralwood) | MS          | 1 N Na\textsubscript{2}CO\textsubscript{3} | WLS, PPS, EIS, HES, TS, AIS         | IE ascends with IC and descends with temperature  
Langmuir isotherm  
Inhibition is exothermic and spontaneous in nature  
Physical adsorption | [18]      |
| 6 | Origanum majorana (sweet marjoram) | MS          | 0.5 M chloride medium            | TS, PPS, DFT                        | Physisorption  
Inhibition is exothermic  
Maximum IE as 90% | [19]      |
| 7 | Ricinus communis (castor oil plant) | Steel       | 3.5% NaCl                        | WLS, PPS, EIS                       | Protective film is formed  
Mixed type inhibition  
Temkin adsorption isotherm | [20]      |
| 8 | Allium sativum (Garlic)     | MS          | 3.5% NaCl, 1M HCl and 1M H\textsubscript{2}SO\textsubscript{4} | FTIR, WLS, PPS, EIS, SEM          | Protective layer is formed on mild steel surface  
Inhibition efficiency increases with inhibitor concentration | [21]      |
| 9 | Rice straw (paddy straw)    | Steel       | 3.5% NaCl                        | WLS, PPS, EIS, XRD                 | IE directly proportional to the extract concentration  
Maximum IE as 92% | [22]      |
| 10| Rice straw                  | Steel       | 3.5% NaCl                        | WLS                                 | Pitting corrosion and oxide | [23]      |
| Plant Type                                      | Extracts/Concentration | Method(s) | Film/Inhibition Characteristics                                                                 | Reference |
|------------------------------------------------|------------------------|------------|--------------------------------------------------------------------------------------------------|-----------|
| Mature areca nut husk extract (areca-nut)      | 0.5 M NaOH             | WLS, PPS, EIS, SEM, FTIR | Film growth are formed on metal. Rice straw extracts give better result as compared to lignin and ethylene glycol. | [24]      |
| Azadirachta indica (neem), Punica granatum, Momordica charantia (bitter gourd) | NaCl                   | WLS, PPS, EIS, SEM | Maximum IE as 92% in 0.5 M NaOH medium. Protective film forms on metal surface. Langmuir isotherm model. Mixed type inhibition. Corrosion current ($i_{corr}$) decreases with plant extract concentration. | [25]      |
| Morinda lucida (Brimstone tree)                | Steel rebar            | NaCl       | Maximum IE as 93 %. CR decreases with IC.                                                      | [26]      |
| Ricinus communis (castor oil plant)            | NaCl                   | WLS, PPS, EIS, SEM | Maximum IE as 85%. Inhibition efficiency found to be 85%. Anodic inhibitor. Chemisorption.       | [27]      |
| Vernonia amygdalina (bitter leaf)              | Steel rebar            | NaCl       | CR decreases with inhibitor. Maximum IE as 91%.                                               | [28]      |
| Centella asiatica and Nicotiana rustica, (Kola leaves and tobacco extract) | 5% sodium chloride solution | WLS, PPS, EIS | CR decreases with inhibitor. Protective film form on the metal surface with extract.             | [29]      |
| Chamaerops humilis (saw palmetto)             | 3 % NaCl               | WLS, PPS, EIS, AIS | Phytochemical screening showed that Polyphenols, Catechol, Gallic Tannins, Flavonoids, Saponins, Terpenoids, Anthracenosides and Cardiac glycosides present in extract. | [30]      |
| Phyllanthus muellerianus (Bhui Aamla)          | 3.5 % NaCl             | WLS, PPS, AIS | Inhibition efficiency as 97.96%. Langmuir adsorption                                             | [31]      |


| 19 | Olea europaea (Olive leaf) | Mild steel | 0.1M NaOH + 0.5 M NaCl | isotherm  
- physisorption | WLS  
- EIS  
- Mixed type inhibition  
- 91.9% as inhibition efficiency | [32] |

WLS- Weight loss study, PPS- Potentiodynamic polarization study, AIS – Adsorption isotherm study, TS – Thermodynamic study, HES- hydrogen evolution studies, DFT- density functional theory

2. Mechanism of green corrosion inhibitor

Mechanism of corrosion inhibition process occurs by three ways and the schematic representation of the mechanism is shown in Figure 1. Adsorption of inhibitor molecules on the metal surface might be physisorption (physical interaction) when electrostatic interaction takes place between the inhibitor molecules and metal surface (Figure 1a). Second way is by sharing or transfer of electrons from inhibitor molecules to metal surface (chemical bond) which results in chemisorption (chemical interaction) (Figure 1b). Last way is the comprehensive adsorption route, in which the inhibitor molecules are adsorbed on the surface of metal and protective film forms on the metal surface and blocks the dissolution process by combination of both physical and chemical interactions (Figure 1c) [24].

![Image](https://via.placeholder.com/150)

**Figure 1.** Mechanism of corrosion inhibition of mild steel in the presence of inhibitor molecules.

In the alkaline medium, a passivation layer is formed on the metal surface and reduces the corrosion rate (Figure 2a). However, in the presence of chloride ions, the passivation layer is ruptured and corrodes at a faster rate (Figure 2b). Hence, a corrosion inhibitor is essential to mitigate the corrosion of metal in the alkaline medium containing chloride ions (Figure 2c).
Figure 2. Mechanism of corrosion inhibition using green inhibitors in the alkaline medium containing chloride ions.

It can be summarized that the inhibitor efficiency is directly proportional to inhibitor concentration and corrosion rate is inversely proportional to inhibitor concentration. Based on the potentiodynamic polarisation study, most of literature reports that the plant extracts obeys the mixed-type inhibition. Protective film formed on the surface of metal is confirmed from SEM photographs. We conclude that corrosion prevention mechanism is based on absorption of inhibitor molecules on the metal surface and by using green inhibitors in the alkaline medium containing chloride ions. As green corrosion inhibitors are derived from plants, it is cost effective and biocompatible to environment. However, in the future it can be surely stated that green inhibitors will continue to be used for corrosion prevention.

3. Conclusion

Assessment of mild steel corrosion in an alkaline environment with various green corrosion inhibitors has been reviewed. It is important to prevent the metal from corrosion through environment sustainable technology. Green corrosion inhibitor is one of the best solutions to mitigate the problem of corrosion in an alkaline medium. It is important to point out the green corrosion inhibitors are economical, harmless to the environment. As plant extracts are used, it is environmentally benign, easily available and natural resource. In near future, toxic inhibitor materials will be replaced with green corrosion inhibitor to minimize the corrosion process. In the alkaline medium containing chloride, it is very challenging to identify the green corrosion inhibitor, as the passivation layer gets damaged in the presence of chloride in the alkaline environment.

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