



ORIGINAL ARTICLE

Synergistic inhibition effects between leaves and stem extracts of *Sida acuta* and iodide ion for mild steel corrosion in 1 M H₂SO₄ solutions

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Abstract The synergistic action caused by iodide ions on the corrosion inhibition of mild steel in 1 M H₂SO₄ by leaves and stem extracts of *Sida acuta* was studied using weight loss and hydrogen evolution methods at 30–60 °C. It was found that the leaves and stem extracts of *S. acuta* inhibited the acid induced corrosion of mild steel. Addition of iodide ions enhances the inhibition efficiency to a considerable extent. The inhibition efficiency increases with increase in the iodide ion concentration but decreases with rise in temperature. Adsorption of the extracts alone and in combination of iodide ion was found to obey Freundlich adsorption isotherm at all temperatures studied. Inhibition mechanism is deduced from the temperature dependence of the inhibition efficiency as well as from assessment of kinetic and activation parameters that govern the processes. The synergism parameter (S_1) is defined and evaluated from the inhibition efficiency values. This parameter for the different concentrations of iodide ions from the two techniques employed is found to be greater than unity indicating that the enhanced inhibition efficiency of the extracts caused by the addition of iodide ions is due to synergism.

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1. Introduction

Iron and iron-based alloys of different grades are extensively used in numerous industrial and engineering applications, including construction and designs, where they are deployed in various service environments containing acids, alkalis and salt solutions. These service environments readily lead to inevitable corrosion of exposed surfaces of the metal because of their aggressive nature. It is a general consensus that the best method to protect the metal deployed in these corrosive environments is to add corrosion inhibitors (Ashassi-Sorkhabi and Nabavi-Amri, 2002; Migahed and Nassar, 2008; Fouada and Ellithy, 2009). To this end, the use of organic and inorganic

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substances to inhibit corrosion of metals in many environments is well established. Unfortunately, most of the organic and inorganic inhibitors are toxic, very expensive and environmentally unfriendly. Due to increasing environmental awareness and adverse effect of some chemicals, an alternative has to be sought to replace inorganic and organic inhibitors to foster sustainable greenness to the environment.

These nontoxic, benign, inexpensive, renewable and readily available alternative corrosion inhibitors have been found in different parts of plant extracts (Okafor et al., 2008, 2010; Oguzie, 2008). The use of plant products as corrosion inhibitors are justified by the phytochemical compounds present therein, with molecular and electronic structures bearing close similarity to those of conventional organic inhibitor molecules (Oguzie et al., 2010).

Despite the broad spectrum of organic/naturally occurring compounds as corrosion inhibitors, the final choice of the appropriate inhibitor for a particular application is restricted by several factors. One factor is the vast variety of possible corrosion systems coupled with the specificity of action of most acid inhibitors which often necessitates the use of a combination of additives to provide multiple effects required for effective corrosion inhibition. This has resulted in studies to identify co-operative (synergistic) effects among corrosion inhibiting species. Synergism is an effective method to improve the inhibitive performance, to decrease the amount of usage, to diversify the application of inhibitor in acidic media. It plays an important role not only in theoretical research on corrosion inhibitors but also in practical work (Li et al., 2009). Some authors have reported on synergistic inhibition effects between organic inhibitors and halide ions (Cl^- , Br^- , and I^-) (Feng et al., 1999; Larabi et al., 2004; Okafor and Zheng, 2009; Umoren et al., 2006, 2010), organic inhibitor/metallic ion mixture (Cheng et al., 2007; Li et al., 2007, 2008; Alagta et al., 2007; Morad, 2007) as well as organic inhibitor/organic inhibitor mixture (Qu et al., 2007; Rammelt et al., 2008; Hosseini et al., 2003; Okafor et al., 2010; Ehteshamzadeh et al., 2006) on steel corrosion in acidic solution. However, literature reports on synergistic inhibition effects between plant extracts and halide ions are very scanty. Synergistic corrosion inhibition of mild steel in 2 M HCl and 1 M H_2SO_4 by leaf extracts of *Occimum viridis* (OV) and halide ions has been reported (Oguzie, 2006). The efficacy of *Telfaria occidentalis* extract as a corrosion inhibitor for mild steel in 2 M HCl and 1 M H_2SO_4 solutions and the effect of halide additives on the inhibition efficiency have been reported (Oguzie, 2005). The inhibiting action of the calyx extract of *Hibiscus sabdariffa* on mild steel corrosion in 2 M HCl and 1 M H_2SO_4 and synergistic effect of halide ions have also been studied (Oguzie, 2008). Oguzie et al. as well pointed out synergistic influence of iodide ion on mild steel corrosion inhibition in acid solutions by aqueous extracts from *Garcinia kola* seeds (Oguzie and Onuchukwu, 2007). Eddy et al. observed that addition of Br^- and I^- ions to *Lasianthera africana* (Eddy et al., 2009a) and *Gnetum african* (Eddy et al., 2009b) leaves extract antagonized inhibition while Cl^- exerted synergistic effect for mild steel corrosion in H_2SO_4 solution. Synergistic inhibition effect between I^- ion and *Dacrodyes edulis* (Oguzie et al., 2010) for mild steel in acidic media has also been reported. We have also reported in our laboratory synergistic corrosion inhibition between halide ions and natural exudate gums of *Raphia hookeri* (Umoren et al.,

2008) and *Pachylobus edulis* (Umoren and Ekanem, 2010) for mild steel in acidic medium.

The present work continues to focus on the application of plant extracts for metallic corrosion control and reports on the inhibiting effects of the leaves and stem extracts of *Sida acuta*, including the synergistic effect of iodide ion additive for mild steel (1005 AISI Grade) corrosion in 1 M sulphuric acid solution at 30–60 °C using weight loss and hydrogen evolution (via gasometric assembly) techniques.

2. Experimental

2.1. Materials

The mild steel sheets used for this study were sourced locally. Each sheet was 0.04 cm in thickness and has the following composition (wt%): C = 0.13; Si = 0.18; Mn = 0.39; P = 0.40; S = 0.04; Cu = 0.025 and the balance Fe. It was mechanically press cut into 5 × 4 cm coupons. They were abraded with different grades (# 400, 600, 800 and 1000) silicon carbide paper, degreased in absolute ethanol, dried in acetone and stored in a moisture-free desiccator prior to use. The corrosive medium was 1 M H_2SO_4 prepared from 98% analytical grade supplied by Sigma–Aldrich. Deionized water was used for the preparation of all reagents.

2.2. Preparation of the *S. acuta* extracts

The leaves and stem of *S. acuta* were sun dried and ground to powder using a manual blender. One kilogramme of the dry powdered samples was extracted using absolute ethanol for 48 h. The extract was concentrated initially using vacuum evaporator and finally by evaporation to dryness on a steam bath to obtain a solid residue devoid of ethanol. From the solid residue, different concentrations (0.1–0.5) g were weighed and then dissolved in one litre of 1 M H_2SO_4 solution for weight loss and hydrogen evolution measurements.

2.3. Weight loss measurements

Weight loss measurements were conducted under total immersion in stagnant aerated condition using 250 mL capacity beakers containing 200 mL test solution at 30–60 °C maintained in a thermostated water bath. The mild steel coupons were weighed and suspended in the beaker with the help of rod and hook. The coupons were retrieved at 2 h interval progressively for 10 h, immersed in a solution of 20% NaOH containing 200 g/L zinc dust at room temperature, scrubbed with bristle brush under running water, dried in acetone and reweighed. The weight loss, in grammes, was taken as the difference in the weight of the mild steel coupons before and after immersion in different test solutions. Tests were performed for the free acid solution, solution of 0.5 g/L leaves and stem extracts of *S. acuta* alone and this concentration of the extracts in combination with different concentrations (0.5–5 mM) KI at different temperatures. The experiments were repeated three times to ensure good reproducibility. The standard deviation values among parallel triplicate experiments were found to be smaller than 5%, indicating good reproducibility. From the weight loss values, corrosion rates were computed using the expression:

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