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A comparative study of leaves extracts for corrosion inhibition effect on aluminium alloy in alkaline medium

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Abstract This paper deals with the comparative inhibition study of some plants leaves extract namely *Cannabis sativa* (CS), *Rauwolfia serpentina* (RS), *Cymbopogon citratus* (CC), *Annona squamosa* (AS) and *Adhatoda vasica* (AV) on the corrosion of aluminium alloy (AA) in 1 M NaOH. The corrosion tests were performance by using gravimetric, electrochemical impedance spectroscopy (EIS), potentiodynamic polarization and linear polarization resistance (LPR) techniques. RS showed maximum inhibition efficiency (η%), 97% at 0.2 g L^{-1}. Potentiodynamic polarization curves justified that all the inhibitors are mixed-type. Surface morphology of AA is carried by scanning electron microscopy (SEM) and atomic force microscopy (AFM).

1. Introduction

Aluminium and its alloys are finding wide applications in the various industries such as automotive, aerospace, construction and electrical power generation. Aluminium, with high energy density (8.1 kW h kg^{-1}) and an electrode potential of 2.35 V vs. standard hydrogen electrode (SHE) in alkaline medium, has emerged as one of the most promising anode materials in Al–air cells [1]. These cells often utilize aluminium–alkaline solution systems. The corrosion (inherent dissolution) of aluminium in alkaline solution is detrimental to Al/air battery. It reduces the efficiency of battery and sometimes causes explosion as a result of hydrogen buildup [1,2].

The use of inhibitor is one of the most practical ways of reducing aluminium corrosion in alkaline medium. Few investigators have researched to lower the self-corrosion rate of aluminium through adding chemical compounds in alkaline solution [3–6]. However, most of them are hazardous, expensive and not safe for environment. In view of this, it is necessary to develop environmentally safe corrosion inhibitor for aluminium in alkaline medium; thus, we have chosen plant extracts as environmentally safe inhibitors that can be

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extracted using simpler techniques with low cost. The phytochemicals (includes alkaloids, flavonoids) present in plant extract contain heteroatom such as N, S, O and π-electrons, aromatic ring, through which they adsorb on metal surface and inhibit corrosion.

There are only few reports available on the use of leaves extract as corrosion inhibitor for aluminium in alkaline medium in which authors obtained very good inhibition efficiency at very higher concentration [7–9]. Abiola et al. studied the effect of *Phyllanthus amarus* and *Gossipium hirtsum* leaves extract and found maximum inhibition efficiencies (76% and 97%) at 2.0 and 2.6 g L^{-1} respectively on aluminium corrosion in alkaline medium [7,8]. Abdel-Gaber et al. showed maximum inhibition efficiency (88%) at optimum concentration (9.9 g L^{-1}) in the case of *Ambrosia maritime* leaf extract [9]. In the present study, a very small amount of concentration is sufficient to get better inhibition performance of investigated leaves. We have collected leaves of some medicinal plants; for instance, *Cannabis sativa* (*f.* Cannabaceae) is an annual, dioecious herb originating from Eastern and Central Asia. *Rauwolfia serpentina* (*f.* Apocynaceae), commonly known as Indian snake root, is widely grown in Southeastern Nigeria. *Cymbopogon citratus* (*f.* Poaceae), an herb known worldwide as lemongrass is tropical plant of Southeast Asia. *Annona squamosa* (*f.* Annonaceae), commonly famously known as Custard apple, is native to India. *Adhatoda vasica* (*f.* Acanthaceae), commonly known as Vasaka, is native to Asian countries.

The present investigation deals with the comparative inhibition effects of leaves extract namely *C. sativa* (CS), *R. serpentina* (RS), *C. citratus* (CC), *A. squamosa* (AS) and *A. vasica* (AV) on AA corrosion in 1 M NaOH. No report till date is available on the use of these leaves extracts as corrosion inhibitors for aluminium in alkaline medium. The inhibition performance is evaluated by electrochemical impedance spectroscopy (EIS), potentiodynamic polarization (PD) and linear polarization resistance (LPR) techniques and surface morphology was studied by SEM and AFM investigations.

2. Experimental procedure

2.1. Materials and test solution

The corrosion test was performed on the AA coupons with the composition given in Table 1. The test solution, 1 M NaOH was prepared by dissolving 40 g of NaOH in 1000 mL of double distilled water.

2.2. Preparation of leaves extracts

C. sativa (CS), *R. serpentina* (RS), *Cymbopogon citrates* (CC), *A. squamosa* (AS) and *A. vasica* (AV) plants were collected from the campus of Banaras Hindu University, India. Leaves were dried in oven at 45 °C, and grinded to powder. One gram of the powder was added to 500 mL of 1 M NaOH solution and refluxed for 1 h. Thereafter, the mixture was cooled and filtered. The precipitate was dried and weighed. The extract was concentrated by evaporating the solvent and maintained its concentration to 1000 mg L^{-1}. Leaves extract test solutions were prepared at concentrations of 0.01, 0.05, 0.1 and 0.2 g L^{-1}.

2.3. Inhibitor constituents

The aqueous extract of leaves contains various chemical constituents such as the leaves of *A. vasica* (AV) contain alkaloids vasicine, N-oxides of vasicin, vasicinone, deoxyvasicine and maiontone [10]. Citral, geraniol and myricene are the water soluble active constituents present in the leaves of *C. citrates* (CC) [11]. Various indole alkaloids such as ajmalicine, ajmaline, reserpine and yohimbine are present in the leaf extract of *R. serpentina* (RS) [12]. The leaves of *C. sativa* (CS) contain various water soluble chemical constituents but cannabinoids (tetrahydrocannabinol, cannabidiol, cannabinol, tetrahydrocannabivarin and cannabigerol) are most interesting biologically active constituents [13]. The prevailing compounds of *A. squamosa* (AS) extract were sodium benzoate, butyloctylphthalate, 4-tert-butylcalix [4] arene and isoamylacetate [14]. The major active constituents present in inhibitor solutions are given in Table 2. These constituents contain π-bonds, nitrogen and oxygen atoms in their molecular structures as active centres. The various chemical constituents present in the inhibitor solutions were synergized the inhibition effect of each other.

2.4. Gravimetric and electrochemical experiments

The AA coupons used in gravimetric and electrochemical tests were mechanically cut into $2.5 \times 2.0 \times 0.046$ cm and $7.0 \times 1.0 \times 0.046$ cm dimensions, abraded with (600, 800, 1000 grade) silicon carbide papers, cleaned with acetone and dried at room temperature. Gravimetric experiment was conducted by placing the AA coupons into the test solutions for 3 h, and thereafter the samples were taken out, cleaned with distilled water, degreased with acetone, dried and weighed. The corrosion rate (C_R) was calculated by using following equation [15]:

$$C_R = \frac{87.6 \times w}{atd} \quad (1)$$

where t is the exposure time in hours (h), a is the area of a coupon in cm^2, w is the weight loss in grams (mg) and d is the density of AA in g cm^{-3}.

With the calculated corrosion rate, the inhibition efficiency $\eta\%$ was calculated as follows:

$$\eta\% = \frac{C_R - C_{R(i)}}{C_R} \times 100$$

and surface coverage (θ) values were calculated by the following equation:

Table 1 Chemical composition (wt%) of the AA used.

Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	V	Ga	Al
0.77	0.93	0.02	0.11	0.01	0.01	0.05	0.02	0.01	0.01	Balanced