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Corrosion Inhibition by ALOE *BARBADENSIS* (ALOE VERA) extract as Green Inhibitor for Mild Steel in HNO_3

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ABSTRACT

The corrosion inhibition of **Aloe vera** extract as a green inhibitor of mild steel (MS) corrosion in nitric acid (HNO_3) solutions have been studied using a gravimetric technique for experiments conducted at 30° and 60°C. The results disclose that the different concentrations of the **Aloe vera** extract inhibit MS corrosion and that inhibition efficiency of the extract varies with concentration and temperature. For extract concentrations studied and ranging from 0.055x 10^{-3} to 0.225x10^{-3}gms, the maximum inhibition efficiency was 89.94% and 89.47% both at 0.225x10^{-3} **Aloe vera** at 30° and 60°C, respectively, in 2.0 N HNO_3.

KEYWORDS: Corrosion, Green Inhibitor, Mild Steel, *Aloe Vera* Extract

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INTRODUCTION

Corrosion is the destruction of material resulting from an exposure and interaction with the environment. It is a major problem that must be confronted for safety, environmental, and economic reasons [1] in various chemical, mechanical, metallurgical, biochemical, and medical engineering applications, and more specifically in the design of a much more varied number of mechanical parts which equally vary in size, functionality, and useful lifespan. Several efforts have been made using corrosion preventive practices and the use of green corrosion inhibitors is one of them [2]. To mention but a few, a general review of the chemistry and corrosion control properties of electroactive polymers is known as conductive polymers (CPs) used for corrosion protection in various environments and their potential benefits over common organic barrier coatings has been performed by Zarras et al. [3]. Sol-gel derived hybrid coatings with the example of hybrid organo-ceramic corrosion protection coatings with encapsulated organic corrosion inhibitors have been analyzed by Khramov et al. [4]. Zuo et al. [5] analyzed the influences of sealing methods on corrosion behavior of anodized aluminum alloys in NaCl solutions while the reactivity of polyester aliphatic amine surfactants as corrosion inhibitors for carbon steel in formation water (deep well water) have been studied by Alsabagh et al. [6]. In line with the emergent concept of “Green Chemistry” and the related couple of principles of “Less hazardous synthesis” stating that wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment, and “Safer chemicals” whereby chemical products should be designed to preserve efficacy of function while reducing toxicity, the use of green inhibitors for the control of corrosion of metals [7] and alloys which are in contact with an aggressive environment is an accepted and growing practice [8 9]. Indeed, a large number of organic compounds are presently under study to investigate and optimize their corrosion inhibition potential. All these studies have revealed that organic compounds especially those with N, S, and O show significant corrosion inhibition efficiency. However, a certain proportion of these compounds is not only expensive but also shows some toxicity to living beings [10]. It is needless to point out the importance of cheap and safe inhibitors of corrosion.

Plant extracts and the derived organic species (which are natural molecules) have therefore become important as an environmentally benign, readily available, renewable, and acceptable source for a wide range of inhibitors [11–16]. They are the rich sources of ingredients which have very high inhibition efficiency [10] and are hence termed “*Green Inhibitors*” [14]. Green corrosion inhibitors [17] are biodegradable and do not contain heavy metals or other toxic compounds. The successful use of naturally occurring substances to inhibit the corrosion of metals in both acidic and alkaline environments has been reported by some research groups [18–24] to mention but a few. Research efforts to find naturally organic substances or biodegradable organic materials to be used as effective corrosion inhibitors of a wide number of metals have been one of the key areas in our research group [25].

ALOE VERA PLANT

Aloe barbadensis, one of 450 species of Aloe Vera is a succulent perennial herb which grows up to 160 cm tall, without stem or with a short stem up to 30 cm long, freely suckering and forming dense groups. Aloe Vera is an important medicinal plant which belongs to the family of Liliacea. The gel, which constitutes the bulk of the leaf substance, serves as the water storage organ for the plant. This gel, which may be removed as a semisolid "fillet" before processing, contains more than 200 different substances. Chief among these are polysaccharides, glycoproteins, vitamins, mineral and enzymes.

Aloe Vera gel as commonly called is organic in nature and can be used in the production of green corrosion inhibitors. It is one of the natural inhibitors which have an inhibitive action on the corrosion of metals. Aloe Vera gel is colorless mucilagenious gel obtained from the parenchymaous cell in fresh leaves of Aloe Vera. It contains various active compounds

such as salicylates, magnesium lactate, acemanan, lupeol, campestrol, sterol, linolenic, aloctin and anthraquinones .

This present work was designed as contribution to the growing interest on environmentally benign corrosion inhibitors to assess the corrosion inhibitive properties of Aloe Vera gel in Nitric acid solutions on Mild Steel at 303K- 333K and to carry out Kinetic studies of the reaction.

RESEARCH OBJECTIVES

Mild steel (MS) is one of the most widely used metals in industry and is the most common form of steel (with 0.16–0.29% carbon) as its price is relatively low while it provides material properties that are acceptable for many applications. However, during industrial processes such as acid cleaning and pickling, MS corrodes easily implying that the use of an efficient inhibitor is very much necessary because the useful life of this valuable metal must be prolonged [26]. Due to their industrial applications, several inhibitors have either been synthesized or chosen from organic compounds having heteroatoms in their molecular structures and some research on the use of natural occurring substances has also been intensified. Eddy and Ebenso [27] have recently studied the inhibition of the corrosion of MS by ethanol extract of *Musa sapientum* peels in H_2SO_4 has using gasometric and thermometric methods, whereas Eddy et al. [26] have additionally analyzed the adsorption and inhibitive efficiencies of amino-1-cyclopropyl-7-[(3*R*, 5*S*) 3, 5-dimethylpiperazin-1-YL]-6, 8-difluoro-4-oxo-uinoline-3-carboxylic acid on MS corrosion using gasometric and thermometric techniques and found it to be a good inhibitor for the corrosion of MS in H_2SO_4 solution. Other earlier studies on corrosion inhibition of MS include the study of alternating current and direct current of temperature effect on MS corrosion in acid media in the presence of benzimidazole derivatives by Popova et al. [28], the inhibition of MS corrosion in sulfuric acid using indigo dye and synergistic halide additives in aerated sulfuric acid solutions at 30–50°C by Oguzie et al. [29] and the inhibitory mechanism of MS corrosion in 2 M sulfuric acid solution by methylene blue dye using thermometric and gravimetric techniques by Oguzie et al. [30]. All the more, in pursuit to find natural corrosion inhibitors, several studies have also been focused on the testing of certain plant extracts for the said purpose. Orubite and Oforka [31] have studied the inhibition of the corrosion of MS in hydrochloric acid solutions by the extracts of leaves of *Nypa fruticans* Wurmb, Oguzie [32] investigated the efficacy of *Telfaria occidentalis* extract as a corrosion inhibitor for MS in 2 M HCl and 1 M H_2SO_4 solutions, respectively, and assessed the effect of temperature and halide additives on the inhibition efficiency, whereas Sethuraman and Bothi Raja [33] evaluated the corrosion inhibition potential of *Datura metel* in acid medium on MS with a view to develop green corrosion inhibitors. Later, Li et al. [34] used berberine that was abstracted from *coptis chinensis* and its inhibition efficiency on corrosion of MS in 1 M H_2SO_4 was investigated through weight loss experiment, electrochemical techniques, and scanning electronic microscope (SEM) with energy disperse spectrometer (EDS). Oguzie [35] has conducted studies on the inhibitive effect of *Occimum viridis* extract on the acid corrosion of MS, and Chauhan and Gunasekaran [36] have investigated the inhibition effect of *Zenthoxylum alatum* plant extract on the corrosion of MS in 5 and 15% aqueous hydrochloric acid solution by weight loss and electrochemical impedance spectroscopy (EIS). Lately, Okafor et al. [37] have probed the inhibitive action of leaves (LV), seeds (SD), and a combination of leaves and seeds (LVSD) extracts of *Phyllanthus amarus* on MS corrosion in HCl and H_2SO_4 solutions using weight loss and gasometric techniques.In the present study, we are trying to study corrosion of MS and the inhibition of the corrosion process by Aloe vera extract. In the least of a positive result would help reduce the economic cost of corrosion control as well as decrease the subsequent environmental threats from inhibitor usage because Aloe vera extract is non-toxic and biodegradable.

RESULTS AND DISCUSSIONS

Table 1 shows values of corrosion rate (CR) of MS in all the concentrations of HNO_3 studied and it shows that CR increases with an increase in HNO_3 concentration. The same trend of increasing CR is observed for either temperature studied in the experiments. Table 2 shows the CR for the corrosion of MS at 1.0, and 2.0 N HNO_3 in the absence and presence of AZI extract at 303 and 333 K. It may be observed from the data in Table 2 that an addition of an increased concentration of the inhibitor generally retards the CR of MS in the acid solutions. This is also seen and supported from the decreasing change in mass loss taking place at a particular acid concentration corresponding with an increase in inhibitor concentration (Figures 1 and 2).

Table 1.Corrosion rate for the corrosion of MS in HNO_3 at 303 and 333 K.

Concentration of HNO_3 (N)	**CR (303 K)**	**CR (333 K)**
1.0	0.5519	1.5535
2.0	2.9847	3.3043

Concentration of Aloe vera extract (gms)	**Corrosion rate (mmpy)**			
	1.0 N HNO_3		**2.0 N HNO_3**	
	303 K	333 K	303 K	333 K
Uninhibited	0.5519	1.5535	2.9847	3.3043
$0.055x10^{-3}$	0.4281	0.7592	1.0073	2.7575
$0.100 x10^{-3}$	0.3772	0.7115	0.7643	2.2793
$0.138 x10^{-3}$	0.2899	0.5774	0.5549	2.0836
$0.171 x10^{-3}$	0.2628	0.4110	0.4058	0.9722
$0.200x10^{-3}$	0.1779	0.2070	0.3827	0.6033
$0.225x10^{-3}$	0.0976	0.1726	0.3098	0.3611

Effect of Aloe vera (Aloe Barbedensis) and acid concentration

From Tables 1 and 2, it is found that the rate of corrosion of MS is affected by concentration of HNO_3, temperature, and concentration of Aloe vera extract. When comparing Figures 1 and 2, it is deduced that the rate of MS corrosion increases as the concentration of HNO_3 increases and also increases as the temperature is increased. An analysis and interpretation of trends in Figure 1 (or Figure 2) show that corrosion increases as the concentration of the acid increases, confirming that the rate of corrosion of MS in HNO_3 increases with concentration. The mass loss taking place and recorded at the different concentrations of the Aloe vera extract are lower than that of the blank solution (for the two acid concentrations) indicating that different concentrations of the Aloe vera extract retard the corrosion of mild steel. It is supposed to be due to adsorption of Aloe vera extract on the surface of MS.

Effect of temperature

Figures 1 and 2 hence show the mass loss plots for the corrosion of MS in the presence of different concentrations of the Aloe vera extract at 303 and 333 K, respectively. Comparing these trends, it is found that at a fixed concentration of the inhibitor and a fixed acid concentration, the mass loss taking place at 333 K is in most of the instances higher than that occurring at 303 K. This indicates that the inhibition efficiency of Aloe vera extract decreases with increase in temperature. The decrease may be due to internal competition between forces of adsorption and desorption of the specific inhibitor molecule(s) participating in the corrosion inhibition reaction(s) at the active sites on the MS surface. These same competing forces of adsorption and desorption may also explain the occasional discrepancies in mass loss change observed in Figures 1 and 2. From Table 3, it can also be appreciated that the inhibition efficiency of Aloe vera extract varies with its concentration. Optimum values of inhibition efficiency were obtained at an extract concentration of $0.225x10^{-3}$ gms, while the least values were obtained at an extract concentration of $0.055x10^{-3}$ gms. The differences between the trends for inhibition efficiency of Aloe vera extract obtained at 303 and 333 K at the two acid concentrations over the range of Aloe vera concentrations presently studied strongly suggest that the mechanisms of adsorption of the inhibitor on the MS surface is predominantly by physical adsorption. For a physical adsorption mechanism, inhibition efficiency of an inhibitor decreases with temperature, whereas for a chemical adsorption mechanism, values of inhibition efficiency increase with temperature 38-39. Following the logic of the latter statement, it may be deduced from Table 3 that for HNO_3 concentrations of 1.0 and 2.0 N, for Aloe vera concentrations up to $0.225x10^{-3}$ gms, chemical adsorption is involved in the corrosion inhibition reactions.

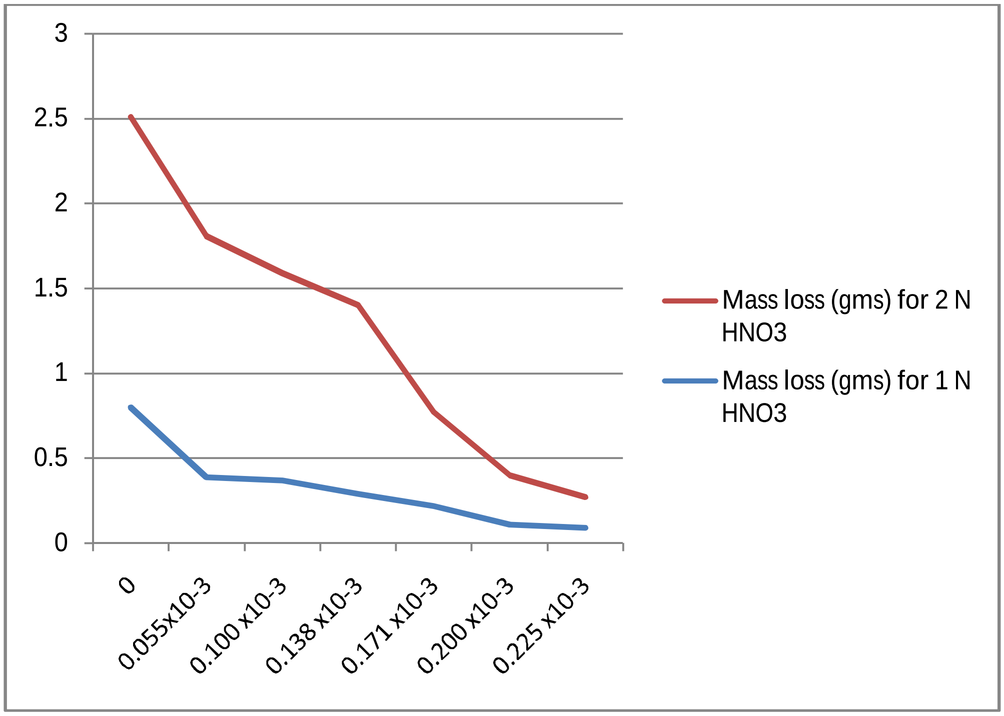

Figure 1. Mass loss changes (g) from Aloe vera concentrations in acidic media at 333 K.

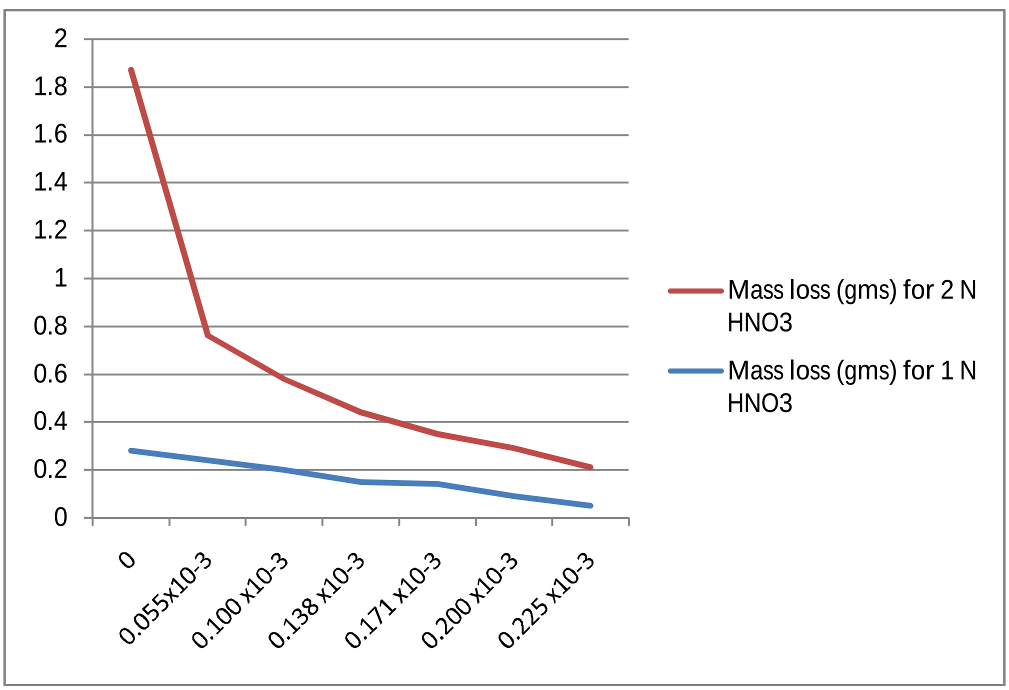

Figure2. Mass loss changes (g) from Aloe vera leaves concentrations in acidic media at 303 K.

Table 3.Inhibition efficiencies of MS corrosion in 1.0 and 2.0 N HNO_3 solutions containing Aloe vera extract

Concentration of Aloe vera extract (gms)	**Inhibition efficiency (%)**			
	1.0 N HNO_3		**2.0 N HNO_3**	
	303 K	333 K	303 K	333 K
0.055×10^{-3}	14.29	51.25	14.29	51.25
0.100×10^{-3}	28.57	53.75	28.57	53.75
0.138×10^{-3}	46.43	63.75	46.43	63.75
0.171×10^{-3}	50.00	72.50	50.00	72.50
0.200×10^{-3}	67.86	86.25	87.42	83.04
0.225×10^{-3}	82.14	88.25	89.94	89.47

Aloe vera (Aloe Barbedensis) extract stock solution

The stock solution of the Aloe vera extract was prepared by removing the outer peel from both sides of aloe vera leaves and collected all the gel with the help of knife and placed that gel in a blender to make it even and smooth. The contents of the extract become smooth and was kept in a refrigerator at low temperatures of 2°C in order to prevent the contents from being altered or degraded due to the chemical, physical, and biological reactions it might otherwise undergo oxidised due to open air exposure.

Mild steel (MS) coupon specimen preparation

Rectangular specimen sheets of MS were mechanically pressed cut to form different strips, each of dimension 7.7 cm long x 2.6 cm wide x 0.042 cm thick. The MS used in the experiments had the following composition: C: 0.240; Mn: 0.470; Si: 0.28; Ni: 0.043; Cr: 0.061; Mo: 0.021; S: 0.020; P: 0.017; and the remainder was Fe. Each strip was degreased by washing with ethanol, dried in acetone, and preserved in a dessicator. All reagents used for this study were Analar grade and double distilled water was used for their preparation. Specimens containing a small hole of 2 mm diameter near the upper edge were used for the determination of CR. The working surfaces of the MS strips were carefully and lightly polished with grade P600 SiC polishing paper in order to remove any impervious oxide layer and eliminate the reactions that would have otherwise taken place with the acid and the oxide layer.

Inhibition efficiency (I) and degree of surface coverage (θ)

The mass loss method was employed for a room temperature at 303 and 333 K. In this procedure, the mass loss of the metal in uninhibited (with no Aloe vera extract) and inhibited solutions was monitored and recorded. A 50 mL of test solutions were analyzed. From this data, the inhibition efficiency (%*I*) and degree of surface coverage (θ) were calculated [27] using Equations (7) and (8), respectively,

$$\%I = \left(1 - \frac{\Delta M_i}{\Delta M_u} \times 100\right) \quad (7)$$

where ΔM_u and ΔM_i are the mass loss of MS in uninhibited and inhibited solutions, respectively.

$$\theta = \left(1 - \frac{\Delta M_i}{\Delta M_u}\right). \quad (8)$$

The CR in millimeters per year (mmpy) has been calculated from Equation (9).

$$CR = \left(\frac{(\text{Mass loss}) \times 87.6}{(\text{Area})(\text{Time})(\text{Metal density})}\right) \quad (9)$$

where mass loss is expressed in mg, area is expressed in cm^2 of metal surface exposed, time is expressed in hours of exposure, metal density is expressed in g/cm^3, and 87.6 is a conversion factor. The density of the MS was 6.86 g/cm^3.

CONCLUSION

From the present study, it is concluded that Aloe vera extract can be used as an inhibitor for MS corrosion in HNO_3 medium. While the green inhibitor molecule supposedly acts by being adsorbed on the MS surface, the overall inhibition is believed to be provided by a synergistic effect. It has also been found that the inhibitive action of Aloe vera extract is basically controlled by temperature and the concentration of the inhibitor.

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