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Enhanced corrosion inhibition effect of tannic acid in the presence of gallic acid at mild steel/HCl acid solution interface

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ABSTRACT

The corrosion inhibition behaviour of tannic acid (TA), gallic acid (GA) and their blends on mild steel in 1 M HCl solution was studied via electrochemical methods, namely, polarization (Tafel plots) and electrochemical impedance spectroscopy (EIS). The surface morphology of mild steel in 1 M HCl, TA alone, and in combination with GA was elucidated using scanning electron microscopy (SEM). The results show that TA can protect mild steel from acid corrosion better than GA. However, inhibition effect of TA can be enhanced by its combination with GA. The adsorption behaviour of TA against steel corrosion obeyed Langmuir adsorption isotherm. Furthermore, polarization results suggest that TA and GA blends behaves as mixed-type inhibitor of predominant anodic effect. EIS results reveal that the charge transfer resistance value of the steel inhibited by TA in combination with GA is significantly higher than that of steel inhibited by TA alone. The SEM images confirmed the enhanced film formation on the steel surface in the presence of TA and GA blended in the ratio 9:1 when compared with TA alone. Quantum chemical calculations have been used to provide insights into the mechanism of interaction of TA and GA on mild steel.

Introduction

Due to its excellent mechanical properties and low cost, mild steel is the constructional material of choice in many chemical and petrochemical industries. The major drawback of mild steel is its low corrosion resistance. Hydrochloric acid solutions are widely used in several industrial processes such as oil well acidizing, acid pickling, acid cleaning, and acid descaling. Because of the aggressiveness of acid solutions, mild steel corrodes severely during these processes [1,2]. The use of corrosion inhibitors is of great practical importance in these processes in order to minimize metallic waste and reduce cost. Most of the well-known acid inhibitors are organic compounds especially those containing N, O, S and P in addition to several multiple bonds in their molecular structure. Nevertheless, most of these compounds are not only expensive but also toxic to humans and the environments. Growing environmental concern and enforcement of strict environmental regulations have compelled researchers to focus on the development of eco-friendly and biodegradable corrosion inhibitors [3–9].

The use of tannins in corrosion protection has been disclosed since 1936 in Great Britain patent no. GB450547. Development and industrial uses of tannins as green corrosion inhibitors in the formulations of pigments, chemical cleaning agents for removing iron-based deposits and oxygen scavengers for boiler water treatment system has been reviewed [10]. Tannic acid (TA) (Fig. 1), which belongs to the class of natural, non- toxic and environmentally friendly compounds has been reported recently as corrosion inhibitor for steel, Cu and Zn in atmospheric condition [11]. The results obtained indicate that steel was the least protected while Cu was the best protected. The corrosion of mild steel in seawater wet/dry cyclic condition is inhibited effectively by tannic acid [12]. The value of the inhibition efficiency obtained from the polarisation curves was 86.05%. Tannic acid acts as a cathodic-type corrosion inhibitor, retarding the cathodic process of the corrosion reactions by forming ferric tannates on the mild steel surface according to the authors. Also recently, tannic acid at 4.2 g/l was found to provide low protection (49.5%) in 2 M HCl and 38.5% at 1 M H_2SO_4 to steel [13].

In order to enhance the performance of tannic acid as mild steel corrosion inhibitor, synergistic addition of gallic acid (GA) (Fig. 1) to TA to boast its inhibition efficiency has been carried out in the present study. Synergistic inhibition, which is an improved

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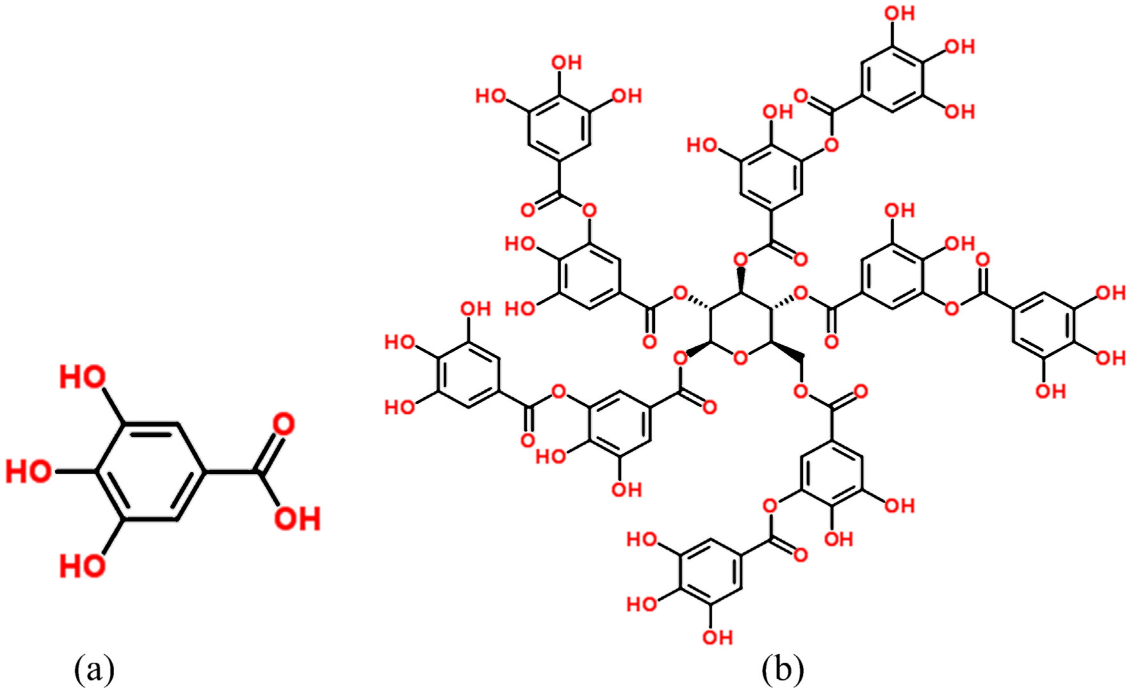

Fig. 1. 2D molecular structures of (a) gallic acid (GA) and (b) tannic acid (TA).

performance of a mixture of inhibitors compared with the individual inhibitors as a corrosion prevention technology for metals and alloys has proven to be an effective method. This method has been widely reported in the literature and also forms the basis for modern inhibitor formulations for industrial applications [14].

The aim of the present work is to investigate the inhibition performance of TA and GA in 1 M HCl and to determine if there is any synergistic effect between the blends of TA and GA towards steel corrosion protection in 1 M HCl. The corrosion protection properties of TA and GA were examined by polarization and electrochemical impedance spectroscopy techniques. Surface morphology of the steel surface in the absent and present of TA and TA–GA blends was investigated using scanning electron microscopy (SEM). Quantum chemical calculations were further employed to provide insights into the reactive behaviour of TA and GA on steel surface.

Experimentals

Test specimens were cut from a typical mild steel pipeline with chemical composition shown in Table 1. The tested coupon is in conformance with API X60 material specifications and the cross-sectional surface was ground with different grade emery papers (400, 600, 800 and 1200), rinsed with acetone, washed thoroughly with doubly distilled water and used as the working electrode. Tannic acid (TA) and Gallic acid (GA) were obtained from Sigma Aldrich, USA and used without any further purification.

Potentiodynamic polarization and electrochemical impedance measurements were done using a conventional three-electrode system (model: Gamry Instrument potentiostat/galvanostat/ZRA (Reference 3000), USA) consisting of a mild steel working electrode (WE) with an exposed area of 0.7855 cm^2, platinum as the counter electrode and a saturated calomel electrode (SCE) as the reference. Tafel curves were obtained by changing the electrode potential automatically from -250 to $+250$ mV versus the open-circuit potential (E_{corr}) at a scan rate of 1 mV/s. Before polarization measurements, the WE was kept in the test solution for 1 h for open circuit potential (OCP) to be reached. Corrosion current density (i_{corr}) was determined from the intercept of extrapolated cathodic and anodic Tafel lines at the corrosion potential (E_{corr}).

Electrochemical impedance measurements were performed in the frequency range 10 mHz to 100 kHz with an a.c. amplitude of 10 mV (rms) at the rest potential. All the experiments have been carried out at 30 °C.

Morphological studies of the carbon steel surface were undertaken by SEM examinations of the surfaces exposed to different test solutions after 24 h using a JSM-5800 LV scanning electron microscope.

Quantum chemical calculations were conducted with Gaussian 03 commercial software [15]. The electronic properties calculation of TA and GA molecules were accomplished by semi empirical PM3 method because of the size of TA.

Table 1
Chemical composition of the tested coupon.

C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu
0.125	0.52	1.83	0.0028	0.0044	0.121	0.091	0.079	0.043	0.296
Co	Ti	Nb	V	W	Pb	B	Sb	Sn	Zn
0.0023	0.0058	0.053	0.078	0.134	>0.030	0.0012	<0.0010	0.081	>0.032
As	Bi	Ta	Ca	Ce	Zr	La	Se	N	Fe
0.0045	<0.0015	0.0100	0.0059	0.0021	<0.0015	0.029	<0.0020	>0.019	<96.2