# THE INHIBITION EFFECT OF TANNIC ACID ON CORROSION BEHAVIOUR OF HSLA STEEL IN PURE WATER

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**Abstract** - The effect of tannic acid on corrosion resistance of HSLA steel in pure water was studied by electrochemical technique using electrochemical impedance spectroscopy (EIS). The EIS data showed the beneficial effect of the addition of tannic acid in reducing the corrosion rate markedly, which indicates that the inhibitor molecules have the ability to reduce the severity of the corrosive attack. Increasing the inhibitor concentration from 1 to 5 g/l contributed further in increasing the corrosion resistance as indicated by the increase of the semicircle diameter in the Nyquist plots. This improvement was ascribed to the high absorbity of tannic acid molecules onto the steel surface so enriching the protectives layers that isolate the surface from the surrounding solution. The thickness and density of the layers are enhanced further as the inhibitor content increases, so giving less opportunity for the solution to penetrate into the steel and consequently preventing its dissolution.

**Keywords** - HSLA Steel, Corrosion, Electrochemical Impedance Spectroscopy (EIS), Inhibition, Tannic Acid, Pure Water

## I. INTRODUCTION

Currently, many types of steel have been developed to meet the increasing demand of the industry [1]. High strength low alloy (HSLA) steel has been used extensively in many applications due to its good mechanical properties as well as its low cost. Some of these applications involve corrosive environments, which lead to the degradation of both mechanical and chemical properties in the long-term, giving rise to replacement and maintenance costs [2]. One of the most popular techniques that has been proven to minimise corrosion is the use of corrosion inhibitors. The most effective inhibitors reported in literature are the organic compounds that contain N, O, S and P [3]. However, most of these inhibitors are considered expensive and toxic to the environment and also to humans [4]. Therefore, more attention is currently given to neutral inhibitors which are eco-friendly and inexpensive. Previous researches showed that tannic acid is effective in improving the corrosion resistance of various metals in various environments. Tannic acid belongs to tannin (plant polyphenol) and it is a mixture of polygalloyl glucoses or polygalloyl quinic acid esters and its chemical formula is given as ($C_{76}H_{52}O_{46}$). Tannic acid is found in Tara pods (Caesalpinia spinosa), gallnuts from Rhus semialata or Quercus infectoria or Sicilian Sumac leaves (Rhus coriaria) [5] and also in fruits and bark of some plants, and it has been used in medication and in some of the manufacturing processes. Qian et al. [6] showed that the corrosion of mild steel in seawater environment could be minimised by tannic acid, giving an inhibition efficiency of 86%. Obot and Madhankumar [7] compared that inhibition effect of tannic acid and gallic acid of mild steel in 1M HCl solution and observed that tannic is more protective, giving an inhibition efficiency of 90% compared to 75% given by gallic acid. The study also showed that increasing the concentration of tannic acid improved corrosion resistance but the improvement rate decreased graduall. Behpour et al. [8] compared the inhibition of tannic acid in two different solutions; 2M HCl and $H_2SO_4$. Although increasing the concentration gave higher inhibition efficiency, the efficiency level was too low in comparison with the other solutions mentioned previously;1M HCl and seawater. The inhibition efficiency did not exceed 35% for 2M HCl and 22% for $H_2SO_4$ at the same concentration of tannic acid. This indicates that the type of corrosive environment plays a vital role in the inhibition efficiency of tannic acid. The previous studies on tannic acid inhibition focused on HCl, $H_2SO_4$and seawater environments but the objective of the present study is to investigate the corrosion inhibition of tannic acid of HSLA steel in a pure water environment, aiming to expand the use of tannic acid in more applications. This is particularly important for piping systems used to transport water as there have been many reports of pipe failure due to corrosion just a few years after installation. Some of the most common consequences include decrease of the efficiency of hot water heaters causing premature failure and premature failure of plumbing systems and fixtures. In the present study, the corrosion behaviour will be evaluated using the electrochemical impedance spectroscopy (EIS) method.

## II. EXPERIMENTAL

### 2.1 Materials and sample preparation

The chemical composition of the steel examined in the current study is (wt.%): 0.4C, 0.6Mn, 0.3Mo, 0.3Si, 0.005P and 0.0045S. The solutions were pure water mixed with different concentrations of tannic acid (g/l): 0, 1 and 5. The tannic acid powder has the molecular structure shown in Figure 1. The samples were abraded with SiC paper from 220 to 1200 grit, degreased with aceton, then rinsed in distilled water and air dried.

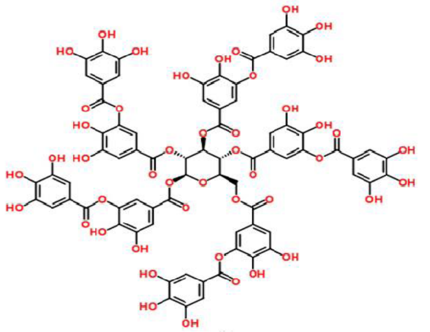

**Figure1. Chemical structure of tannic acid [7].**

### 2.2 Electrochemical experiment

The HSLA steel samples were cubic in shape and had the following dimensions: 1 x 1 x 1 cm. The samples were immersed in the pure water at room temperature. The electrochemical experiment was conducted at room temperature using a PARSTAT 4000 Multichannel Potentiostat equipped with Versa Studio software. The test cell was based on a three-electrode configuration using platinum as a counter electrode, saturated calomel (SCE) as a reference electrode and the sample as a working electrode. The electrochemical impedance spectroscopy (EIS) tests were carried out with an amplitude of 10mV over the frequency range, 100 kHz to 10 m Hz with an AC wave of ±5 mV peak-to-peak overlaid on a DC bias potential. All the measurements were repeated three times for reliability.

## III. RESULTS

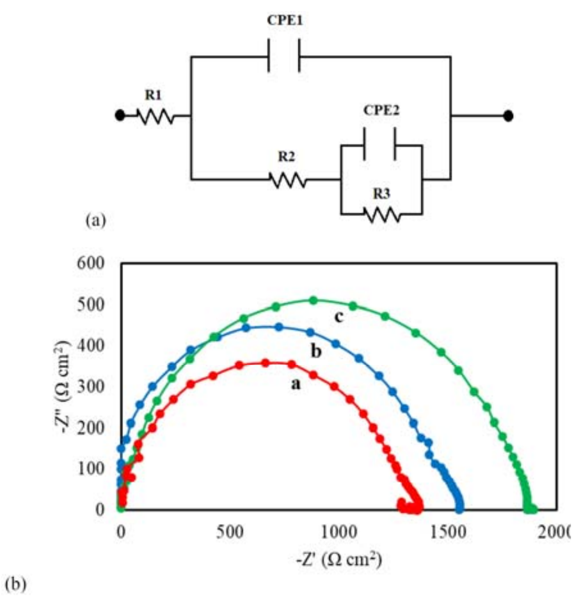


**Figure2. (a) equivalent circuit for fitting the EIS data, (b) Nyquist plots for the HSLA steel immersed in tannic acid at the following concentrations (g/l); (a) 0, (b) 1 and (c) 5.**

The electrochemical response to the impedance tests was best simulated with the equivalent circuits shown in Figure 2(a). The R1 is the solution resistance, R2 is the film resistance, and R3 is the charge transfer resistance, while the CPE is used to replace a double layer capacitance in order to obtain a better fitting. The Nyquist plots of the HSLA steel immersed in pure water with various concentrations of tannic acid, 0, 1 and 5 g/l, are shown in Figure 2(b). It is observed that the absence of the inhibitor gives the smallest semi circle among all the tested samples. However, the addition of the inhibitor improved the corrosion resistance, reflected by the increase of the arc diameter. This behaviour was found to continue further with increasing the inhibitor concentration.

## IV. DISCUSSION

The EIS data provided in Figure 2 gives a clear vision on the corrosion resistance of the HSLA steel under different concentrations of tannic acid. The increase in the arc diameter by increasing the inhibitor content indicates that the inhibitor reduces the dissolution of the steel by increasing its corrosion resistance. At lower contents of tannic acid, the solution continuously attacks the steel surface without noticeable resistance by the steel due to the lesser reliability of the protective layer.

However, increasing the inhibitor content is effective in improving the corrosion resistance because the tannic acid molecules inhibit corrosion via their adsorption onto the surface of the steel [8,9,10]. HSLA steels are alloyed with small contents of various elements that contribute into improving the corrosion resistance of the steel. However, the percentage composition of these elements are not significant so they are not capable of providing sufficient protective layers that can promote the corrosion resistance to meet the industry challenges in this field. The EIS results clearly indicates that tannic acid can compensate for the low alloys content, reflected by the considerable reduction in the corrosion rate especially with increasing the inhibitor content. Tannic acid molecules have a high level of absorptivity so their absorption onto the steel surface promotes the formation of protective layers that can block the active sites and isolate the surface from the surrounding solution. Therefore, higher contents of tannic acid increase the adsorption probability of its molecules, which increases the efficiency of the protective layers that in turn provides more protection to the steel surface from being corroded easily. Moreover, increasing the inhibitor concentration contributes to the thickening of the adsorbed protective layers onto the steel surface, so making it more difficult for the solution to penetrate into the steel and so reduces its dissolution [11]. It is worth mentioning that the efficiency of tannic acid as an inhibitor can vary depending on the grade of HSLA steel. Each grade has its own thermal history, alloying composition and microstructure. Each of these parameters has its own influence on corrosion behaviour either beneficial or detrimental. For example, the addition of Al was reported to enhance the corrosion resistance [12] while the current examined steel is not alloyed with Al, so any comparison made must take into consideration the processing parameters. The current steel was alloyed with minor elements so not to affect the corrosion behaviour or the analyses of tannic acid inhibition mechanism. Although alloying composition is the primary factor in controlling corrosion behaviour of HSLA steel, the microstructure including phases, grain size and precipitates have a considerable effect on corrosion behaviour and must be taken into consideration [13].

## V. CONCLUSIONS

The corrosion behaviour of HSLA steel in pure water using tannic acid as a corrosion inhibitor with various concentrations was investigated based on EIS measurements. With the absence of tannic acid, the steel showed very poor corrosion resistance due to the continuous dissolution of the steel. However, tannic acid serves as an effective inhibitor in pure water environment through the formation of protective layers on the steel surface. This phenomenon occurs as tannic acid is adsorbed onto the surface of the steel and thus obstructs the reaction sites of iron surface. Increasing the concentration of tannic acid improves the corrosion resistance due to the high absorptivity of the acid onto the steel surface that ensures the formation of thicker and denser protective layers that prevent further attack by the solution.

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