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Corrosion Inhibition of Carbon Steel Using Tree Gum in 3.5% NaCl Solution

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ABSTRACT

In this study, the corrosion behavior of carbon steel metal was studied under certain conditions. The experiments were carried out under different conditions, including three temperatures (20, 40, and 60℃) in a 3.5% NaCl solution. The corrosion of carbon steel in 3.5% NaCl solution was inhibited using three concentrations of tree gum: 0, 1, and 3 g. The experiments were performed using polarization and weight loss methods. The results confirmed that the corrosion potential became more negative when the temperature was increased, which led to an enhancement in the corrosion rate. However, an increase in the concentration of the corrosion inhibitor caused the potential to become more positive and reduce the corrosion rate. In conclusion, the inhibition efficacy was close to 90% using the tree-gum inhibitor in a saline medium.

1. INTRODUCTION

The corrosion of metals is the gradual deterioration of the material structure caused by electrochemical or chemical reactions with the environment. Gradual destruction of materials for physical reasons occurs owing to mechanical wear, abrasion, and/or erosion [1].

Metallic surface corrosion can be decreased or controlled by the addition of some chemical materials; this form of corrosion control is called corrosion reduction or inhibition, and the added materials are known as inhibitors of corrosion [2].

Usually, these inhibitors are rated in terms of efficacy of inhibition η and are shown by the equation below [3]:

$$\eta=\frac{(\mathrm{CR})\mathrm{o}-(\mathrm{CR})\mathrm{I}}{(\mathrm{CR})\mathrm{o}}\times 100 \quad (1)$$

Corrosion in both atmospheric and aqueous environments is an electrochemical process. This is because corrosion occurs when electrons transfer between the aqueous electrolyte solution and metal surface [4]. Normally, the current flow moves from a higher potential position to a lower potential position. Hence, in the system, two reactions take place simultaneously, one of which is the discharge of electrons from the metal (electrode) surface, called the anodic electrode.

In neutral aerated salt solutions, there have been many studies on carbon steel corrosion, especially in a solution of sodium chloride, while a few have studied the corrosion of carbon steel in sodium sulfate and Na_2SO_4 as a salt solution [5].

The chemistry of green inhibitors has attracted great interest in the last decade by studying the design of chemical technologies and commercial products with the aim of avoiding toxins and reducing waste [6]. Scientists of corrosion and its engineers are more inclined towards the effects of green corrosion inhibitors that are considered environmentally friendly, readily available, inexpensive, renewable, and ecologically acceptable [7]. Green corrosion inhibitors do not contain toxic compounds or heavy metals and are biodegradable [8].

Natural gum is an indispensable component of the pharmaceutical, cosmetic, and food industries [9]. Many studies on corrosion have been reported for some gum plants (natural), and this gum is generally accepted and has led to the utilization of a given natural depending on its physiochemical and rheological properties [10].

Green corrosion inhibitors intervene in the kinetics of corrosion in various ways, so some of them inhibit the cathodic reactions, while others inhibit the anodic reactions, and in some kinds of inhibitors, both reactions might be inhibited. The mechanisms by which they affect the production of individual substances can be quite complex and are the subject of extensive ongoing research [11].

In electrochemical reactions, polarization can be defined as a perturbation type that results in the production of a dynamic situation and disturbing equilibrium [3]. Polarization measurements are considered very important tools in research to estimate a variety of electrochemical phenomena. Consequently, studies of such measurements of the mechanism of reaction, kinetics of corrosion phenomena, and deposition of metal have been conducted [12]. The polarization types are IR drops, which are the polarization of the activation and concentration polarization [3].

Many units involve the inhibitors addition via units of refining: units of oil or gas production, the system of cooling, etc. The function performs of inhibitor function is the molecules immobilization/metal's surface ions which reduce the corrosion rate.

a) By increasing or decreasing anodic or cathodic reaction.

b) By decreasing the diffusion rate for the metal's surface reactant.

c) Electrical resistance decreases on the surface of the metal.

The nature gum is a good inhibitor of corrosion for the following reasons:

1) Their group of functional, complexes with metal ions on the surface of the metal.

2) The complexes of gum metal take a large area of the surface metal, thereby covering the surface and coating the metal from corrosive representative ready in the solution.

3) The entity of arabinogalactan, glycoprotein, sucrose, and polysaccharide, these compounds contain O and N atoms which are in the middle of adsorption.

4) The gum has the functional group COOH which raises the charge transfer contribution and hence eases inhibition adsorption.

5) All natural corrosion inhibitor gums are less inhibitor toxic, green, and eco-friendly inhibitors [13].

2. LITERATURE REVIEW

In addition to the studies mentioned previously, some studies in the literature have considered the effect of numerous factors on the corrosion and inhibition of metals in different solutions.

Abdallah [14] investigated the effect of a guar gum inhibitor on the corrosion of carbon steel in a 1M H_2SO_4 medium using the loss of weight and polarization of the Tafel method. The results demonstrated that the corrosion efficiency of inhibition increased with increasing gum concentration, which acts as an inhibitor of the type of mixture. The effect of chloride ions on pitting corrosion was analyzed using the potentiodynamic anodic polarization technique.

Arukalam et al. [15] studied the effect of inhibiting the corrosion of 1.0 MHCl medium by xanthan gum using weight loss and polarization measurement techniques. They found that inhibition increased with increasing concentrations of xanthan gum. The effects of temperature and time of exposure were also studied. The inhibition depended on the surface adsorption of the metals, which followed the Teemkin and El-Awaady adsorption isotherms.

Manickam et al. [16] studied the behavior of the tragacanth of powder gum and the inhibition of steel corrosion in sulfuric acid. Researchers have used the technique of weight loss or polarization of potentiodynamics to investigate the technical aspects of the spectroscopy of chemical impedance materials. They found that the inhibition efficacy increased with temperature when the inhibitor concentration increased. In other words, it was noticed that the results of the inhibition efficacy are very acceptable and are compatible with the same studies of technical weight methods, polarization of potentiodynamic, and spectroscopy techniques of electrochemical impedance.

The effect of the corrosion inhibitor serrata gum of Boswellia (BSG) on mild steel was investigated using different techniques such as weight loss, polarization of potentiodynamic (PDP), spectroscopy of impedance of electrochemical (EIS), and microscopy of atomic force (AFM) in 1 M HCl solution at different temperatures (30-60°C) and concentrations has been investigated by Basik et al. [17]. The results show that BSG is a good inhibitor of the corrosion of mild steel in 1MHCl solutions. The inhibition efficacy (η) of the steel in 1MHCl increases when the inhibitor concentration increases. The highest percentage of inhibition efficiency was approximately 91.8% at a concentration of 500 ppm at 30°C.

Asaad et al. [18] studied the behavior of gum arabic nanoparticles (GA.NP) on reinforced concrete exposed to CO_2 environments for 180 days. In addition, the researchers studied steel concrete in the absence and presence of GA.NP by examining the NPs inhibitors on the corrosion processes of concrete inhibitors via inhibitor molecule adsorption over the surface steel by forming protective of thin layers. The inhibitor efficacy was achieved at 0.945 with decreasing the rate to be close to 57×10^{-5} mm per year. It was concluded that the natural green inhibitor GA.NP had a significant corrosion inhibition potential and improved the carbonation resistance of the concrete matrix to acquire durable concrete structures.

3. METHODS

In practice, a laboratory system has been designed to inhibit carbon steel corrosion under variable conditions. The practical part can be classified into two main parts. The first part, free corrosion, is represented by measuring the weight loss for individual metals to estimate the corrosion potential and the average corrosion rates under static conditions, with and without inhibitors at different temperatures. The second part is the polarization of the electrochemical measurements of different concentrations of the inhibitor and the corrosion potential under variable conditions.

In laboratory experiments, the corrosion potential of carbon steel metal as well as the corrosion rate were determined in a static system and at variable temperatures of 20, 40, and 60°C using polarization and weight loss methods. Carbon steel metal was cut to dimensions of 6 × 2.5 cm. After preparation and cleaning, the samples were placed in a test salt medium (3.5% NaCl solution) for 3 h at temperatures of 20, 40, and 60°C and with 0, 1, and 3 g of tree gum inhibitors. Electrochemical polarization measurements were performed using a CS plate as the working electrode with dimensions of 6 × 2.5 cm dimensions. The reference electrode was a saturated calomel electrode (SCE) and graphite was used as the auxiliary electrode. Figure 1 shows the polarization circuit that was monitored manually while the water bath was used to control the temperature with an accuracy of ±1°C. The potential was monitored every two minutes during the experiment.

The preparation of the inhibitor from tree gum is a natural product and was collected from the apricot trees of Iraq, where an amount of apricot tree gum is dried and then ground to obtain the gum powder. Add the required amount of powder to the salt solution until it is homogeneous. The solutions were prepared by dissolving the apricot gum powder in 3.5%NaCl solution at a given concentration. After that, free corrosion and polarization experiments were conducted [13].

3.1 Corrosion rate experiments

3.1.1 Weight-loss method

But before starting every experiment, the carbon steel specimen was polished using 400 and 2000-grid silicon carbide papers, washed with water, and brushed with a plastic brush with running tap water. It is then immersed in methanol for 1 minute, dried with a clean tissue, and then dried by using the electrical oven to a temperature of about 80℃ for 5 minutes. The specimen then was stored in a vacuum desiccator over high activity silica gel until use. The specimen was weighted in mg (W1) by using a digital balance to measure the weight before corrosion and the weight was recorded, after that, the carbon steel specimen was immersed in the 3.5%NaCl solutions at different tree gum concentrations and available temperatures. The specimen is allowed to corrode freely for 3 hours to measure the corrosion rate in the NaCl solutions. At the end of the weight loss [14].

During the experiment, the specimen was washed with water and brushed with a plastic brush with running tap water to remove the corrosion products that were produced on the external surface, submerged in methanol. It was then dried with clean tissue, and then dried by using the electrical oven to a temperature of about 80℃ for 10 minutes, and then weighed in mg (W2).

To calculate the corrosion rate, the following equation is used:

$$CR = W/A.T$$

where, W = mass loss in g, T = time of exposure in day, A= area in m^2, CR is in gmd.

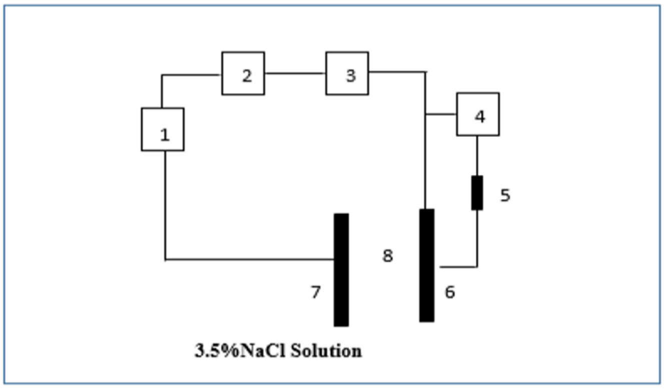
Upon completion of the corrosion testing, observation of microstructures and morphological analyses were done by using optical microscopy (OM) [14].

3.1.2 The polarization method

The electrochemical polarization method was employed to ascertain the corrosion rate by getting the polarization curve. Experimental experiments were conducted at different temperatures. For polarization experiments, a rigged photo is shown in Figure 1 and a schematic diagram of the experimental setup is shown in Figure 1. It comprised a basin, CS specimen (length 60 mm, d=25 mm) as a working electrode, graphite as an auxiliary electrode, a standard calomel electrode (SCE) as a reference electrode, variable resistance (rheostat), power supply for providing the applied voltage, ammeter for current measurements, and voltmeter for measuring the cathode potential.

The procedure included that the electrical circuit was connected to acquire the cathodic and anodic polarization curves. To achieve cathodic polarization, the electrode that works (CS) is linked to the negative terminal of the power supply to function as the cathode, while graphite is connected to the positive terminal to act as the anode. Upon achieving the requisite temperature and establishing the voltage at 8 V, the specimen (cathode) while graphite (anode) were submerged in the solution, and the electrical circuit was activated. Upon initiation of the test run, the stable-state current and potential (against SCE) of the specimen were documented. At each interval, and after a minute had passed, the current and potential were documented with a sweep rate of 5-10 mV. The SCE was consistently positioned at a set distance of 1-2 mm to the cathode (specimen). The specimen was uniformly polarized by adjusting the applied current through a rheostat, beginning with the maximum current flowing through the cell.

After the current became zero, the power supply was turned off, and the specimen was left for an hour and a half to corrode freely. After this period, the power supply was turned on again, and the potentials were measured with the current. The readings were recorded while changing the resistances in the power supply until the current reached zero again. When the current becomes zero, the measured potential is the open circuit potential (OCP) or the corrosion potential (Ecorr) [14].



1:	Ammeter	5:	SCE
2:	Power supply	6:	Working electrode
3:	Resistance box	7:	Anode electrode
4:	voltmeter	8:	Solution

Figure 1. Electrochemical polarization circuit

4. RESULTS AND DISCUSSION

The effect of temperature at 20, 40, and 60℃ and concentrations of tree gum inhibitors 0, 1, and 3 g in salt medium (3.5% NaCl) using the weight loss method is shown in Table 1. It can be noticed that the corrosion rate increased when the temperature increased, and the potential of corrosion became more negative as illustrated in Figures 2 to 4.

Figures 5 to 7 show the polarization of the CS metal at different temperatures and concentrations of the tree gum inhibitor. The limiting current density increased with increasing temperature and decreasing concentration of the gum inhibitor, whereas the potential of corrosion became less negative with decreasing temperature and more negative with decreasing concentration of the inhibitor. This enhancement in the corrosion rate and limiting current density (see Table 2) is attributed to the increase in the effects of activation polarization and oxygen mass transfer. Furthermore, the corrosion potential became more negative owing to an increase in the corrosion process. Therefore, the enhancement in the corrosion current can be attributed to the increase in the number of electrons passing through the surface of the corroded metal. Thus, the voltage becomes more negative and vice versa. In addition, the cathodic reaction that occurs on the surfaces of the metals is represented by the following equations [4, 5]:

$$H^+ + e \rightarrow \mathrm{H_2O} \tag{2}$$

$$2\mathrm{H}^+ + \frac{1}{2}\mathrm{O}_2 + 2e \rightarrow \mathrm{H_2O} \tag{3}$$

From Table 1, it can be clearly seen that the efficiency of the three gum corrosion inhibitors increases with increasing concentration and decreases with increasing temperature, leading to a decrease in the total cathodic reaction and current of hydrogen and oxygen. Hence, the inhibition caused a decrease in the rate of corrosion. Moreover, anodic currents (inhibitor of higher efficiency) increased slightly at high temperatures, as demonstrated in a previous study [11, 18].

Corrosion inhibitors are also adsorbed on the corrosion metal on its surface and form a protective layer. The adsorption of the inhibitor under any condition was either chemisorption or physical adsorption [19, 20].

In Figures 2-4, it is noticeable that the values of the corrosion potential became more negative with decreasing concentrations of tree gum inhibitors, as illustrated in Figure 2. This is caused by the corrosion inhibitor effect on anodic reactions, that is, the anodic reaction of corrosion inhibitors of potential would be less negative, while with decreasing temperature of metals, the values of potentials would be less negative. Additionally, the limiting current density increased with increasing temperature and decreased with decreasing tree-gum corrosion inhibitors (see Table 2), which was caused by decreasing the corrosion rate and bulk oxygen concentration.

Table 1. Temperature and concentration effected of inhibitor (tree gum) on carbon steel metal corrosion rate in air saturated 3.5% NaCl medium at time = 3 hours

T (°C)	C (g/l)	Δw(g)	CR (gmd)	η%
20	0	0.02	179.24	-
40	0	0.031	295.25	-
60	0	0.051	421	-
20	1	0.0041	29.56	84
40	1	0.021	152.75	51.1
60	1	0.026	220.31	47
20	3	0.001	10.01	93
40	3	0.002	17.02	92
60	3	0.0075	65.3	85

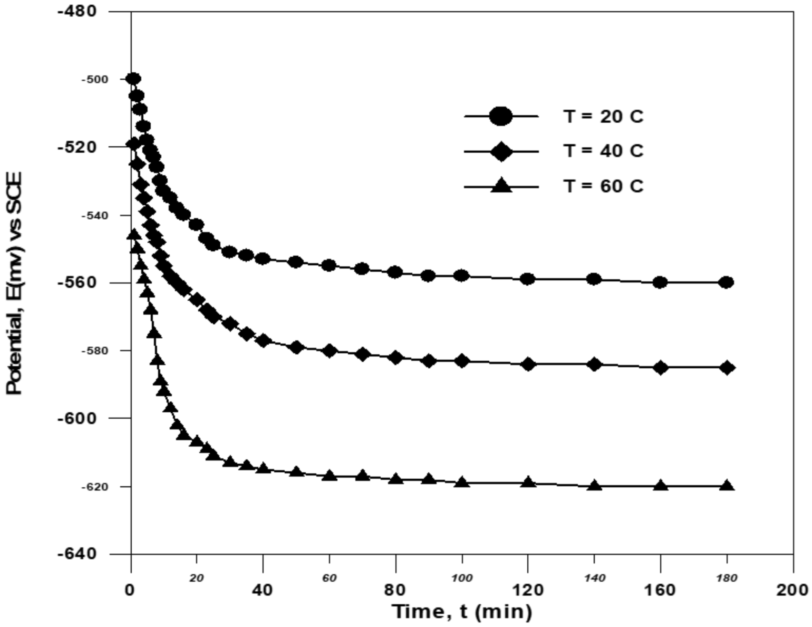


Figure 2. Potential vs time of CS metal in 3.5% NaCl solution without inhibitor at different temperatures

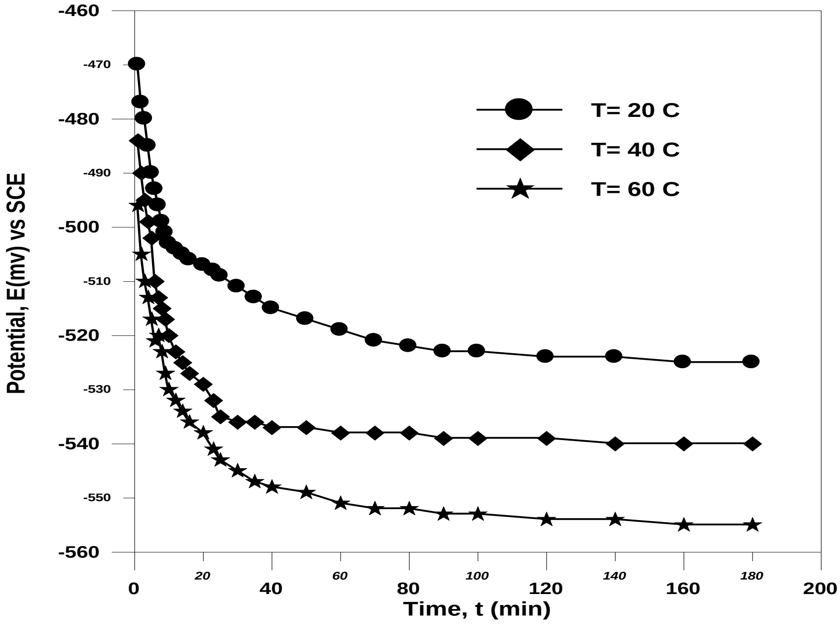


Figure 3. Potential vs time of CS metal in 3.5% NaCl solution and 1g/l tree gum inhibitor at different temperatures

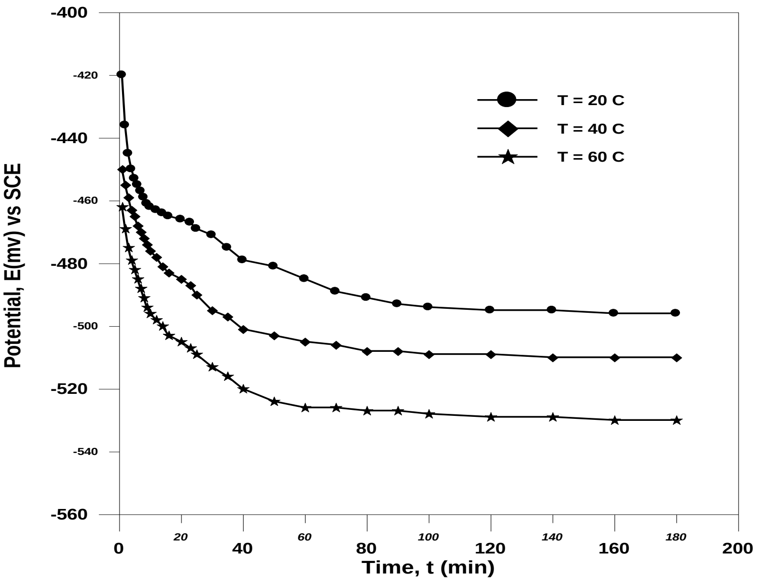


Figure 4. Potential vs time of CS metal in 3.5% NaCl solution and 3 g/l tree gum inhibitor at different temperature

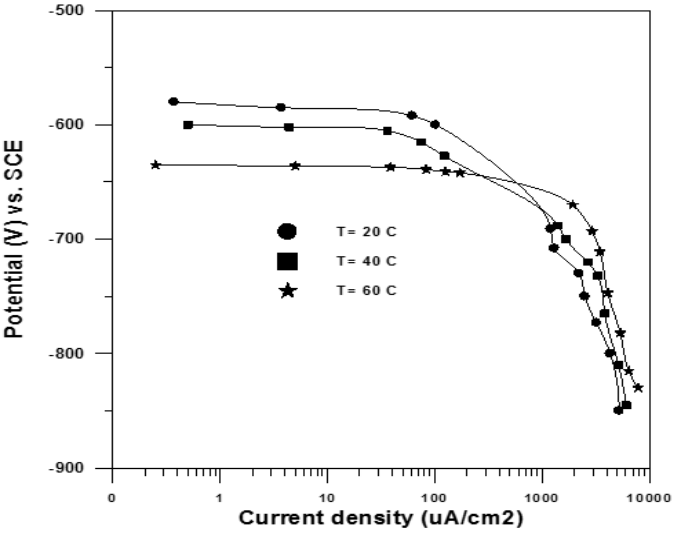


Figure 5. Polarization curve of CS metal in 3.5% NaCl solution without inhibitor at different temperatures

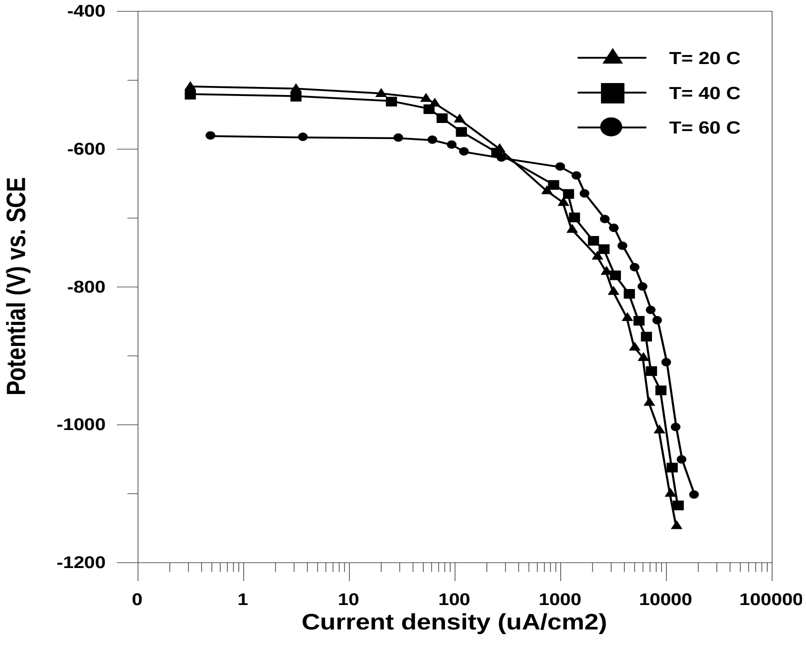


Figure 6. Polarization curve of CS metal in 3.5% NaCl solution with 1g/l tree gum inhibitor at different temperatures

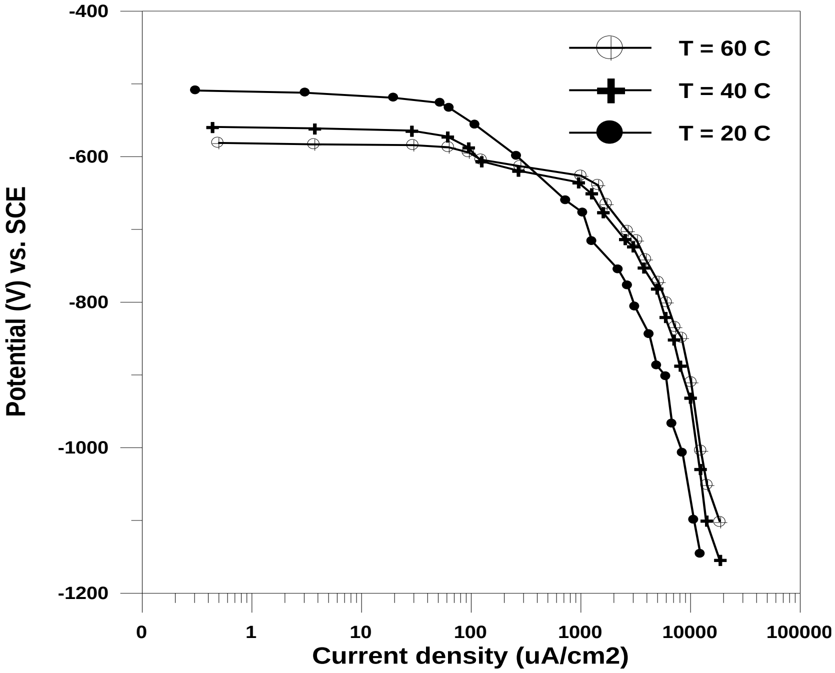


Figure 7. Polarization curve of CS metal in 3.5% NaCl solution with 3g/l tree gum inhibitor at different temperatures

Figures 2-4 show that the corrosion potential had a greater increase in negative values with increasing time (see Table 2). In fact, the corrosion potential always becomes more negative rapidly at the beginning of the CS surface with exposure time to salt media, and then the curve may converge at a slower rate. This is because the OH- ions grouped and formed at a high rate around the electrode. Later, the rate of formation of these ions decreased and revert to a smaller value [21, 22].

Table 2. Effect of temperature and concentration of inhibitor (tree gum) on carbon steel metal corrosion potential (free corrosion curves) and limiting current density (polarization curves) in air saturated 3.5% NaCl medium at time = 3 hours

T (°C)	C (g/l)	Corrosion Potential, E(mv)	Limiting Current Density, µA/cm^2
20	0	-560	2900
40	0	-585	3200
60	0	-620	3400
20	1	-525	2000
40	1	-540	2250
60	1	-555	2500
20	3	-496	1100
40	3	-510	1250
60	3	-530	1500

Figures 5 to 7 show the polarization curves of the potential vs. saturated calomel electrode (SCE) vs. current for the anodic and cathodic regions in the salt solution (3.5%NaCl). The limiting corrosion current density also appeared to increase as the temperature parameter increased, and the inhibitor concentration decreased. Accordingly, when the limiting current density increased, the potential of the metal surface became more negative. This can be interpreted as the increase in, density of limiting which is due to the enhancement of oxygen mass transfer and the effects of Tafel polarization (activation) [22, 23].

The adsorption of chemical and adsorption of physical are two main types of organic adsorption compounds on the surface of metal matter to the metal electronic structure and the compositions of inhibitors.

The ability of the organic compound that acts as a corrosion inhibitor is to be adsorbed on the metal surface to replace water molecules with the organic compound, as shown in the following equation:

$$\mathrm{Inhsol} + \mathrm{nH_2O}_{ads} \leftrightarrow \mathrm{Inhads} + \mathrm{nH_2O}_{sol}$$

Many factors control the adsorption of an inhibitor on the metal surface, such as structure, electronic density, molecular size, inhibitor concentration, temperature and functional groups.

The cathodic and anodic reactions are consistent of OH$^-$ and Fe^{2+}, respectively.

$$\mathrm{Fe} \rightarrow \mathrm{Fe}^2 + 2e^- \tag{4}$$

$$2\mathrm{H_2O} + \mathrm{O_2} + 4e^- \rightarrow 4\mathrm{OH}^- \tag{5}$$

Anodic reaction inhibition of on surface of the metal is done by the formation of Fe^{2+}-gum complex on the carbon steel surface of the anodic area while cathodic reaction gum inhibitor is done by the insoluble material adhesion which is formed by OH- on the metal complex of cathodic area.

5. CONCLUSIONS

Tree gum showed good performance as an inhibitor in salt medium with an efficacy close to 90%. With increasing concentrations of the tree gum corrosion inhibitor, the corrosion potential became less negative in salt solutions (3.5% NaCl solution). However, the corrosion potential showed more negative values with increasing temperature, limiting the current density, and enhancing the corrosion rate (by weight loss) i with increasing temperature of the salt solution.

And recommendations are:

1- Use of other metals such as aluminum, and Magnesium and in the case of impressed current, the high silicon iron.

2- Studying the effect of flow velocity on the green corrosion inhibitor protection and potential decay.

3- Study the effect of other types of salts in the salt water.

4- Study the effect of other gum types as nature corrosion inhibitor in the salt water.

5- Study the effect of pH change.

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