

ENVIRONMENTALLY FRIENDLY MATERIALS FOR THE CONTROL OF CORROSION AND DEPOSITION OF SCALE IN WATER SYSTEMS

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ABSTRACT.

The aim of this study is to conduct laboratory and field studies to investigate the complete assessment of Arghel extract as a novel environmental antiscalant, and corrosion inhibitor. The obtained results will be compared with the available commercial inhibitors. Mineral scales were deposited from the brine solution by cathodic polarization of the steel surface at 40° C. The used evaluation techniques were chronoamperometry, electrochemical impedance spectroscopy (EIS) techniques, optical and scanning electron microscope (SEM) as well as infrared spectroscopy (IR) examination to rank the efficiency of both used inhibitors.

Keywords: Scales; Corrosion; *Arghel* Herbal extracts; Brine solution; EIS; Chronoamperometry; Optical microscope examination; SEM; IR; Electrochemical Impedance Spectroscopy; Potentiodynamic Polarization.

1 INTRODUCTION.

Two of the main problems of great economic impact for cooling systems are scaling and corrosion phenomena. Nearly all problems associated with the use of water for cooling purposes can be attributed to corrosion and scale deposition in pipes and particularly on heating surfaces.

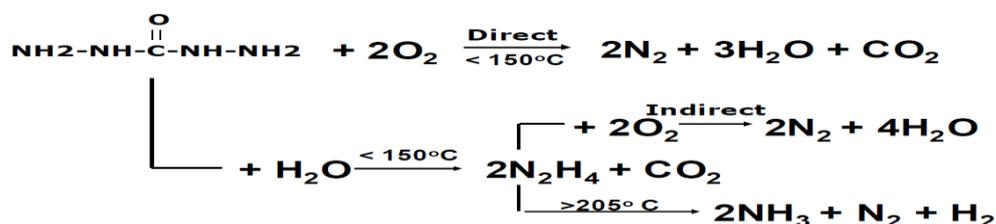
Scaling and corrosion problems were associated with the use of natural hard water in cooling towers during recirculation causing significant economic and technical problems such as decreased system efficiency and increased frequency of chemical cleaning. The physical, chemical and bacteriological effects determine the nature and rate of scaling. (Kavitha et al. 2011), (Abd-El-Khalek et al. 2016), (Gabrilli et al. 2002), and (Li et al. 2016).

The major source of industrial cooling water in Alexandria, the largest industrial zone of Egypt, is the raw water from Noubaria Canal. Salts are usually removed and treated by adding commercial anti-corrosion chemicals such as Carbohydrazide to act as oxygen scavengers and adding anti-scalent such as Trisodium Phosphate (TSP). This cooling water system was studied in one of petrochemical companies, which consumes huge quantities of these commercial chemicals that are harmful to environmental impact.

This study has aimed at replacing those chemicals by an environmental friendly herbs *Arghel* extract formulation.

In commercial water treating chemicals, the most widely used material in this application is Carbohydrazide that reacts readily with oxygen at low temperatures and pressures, and passivates the

metal of the boiler system. Carbohydrazide can (and does) break down to the damaging hydrazine compound above temperatures of 350°F (180°C) to scavenger oxygen, but this conversion is not necessary for oxygen scavenging activity because it reacts directly with oxygen. (Prinva et al. 2017):



2 MATERIALS AND METHODS.

2.1. Materials.

2.1.1. Calcium Chloride brine solution.

Distilled water and analytical reagent grade NaCl, NaHCO₃, Na₂CO₃, Na₂SO₄ and CaCl₂ were used for preparing solutions. The CaCl₂ brine solution was prepared to a concentration of 0.7 M NaCl, 0.0025 M NaHCO₃, 0.028 M Na₂SO₄ and 0.01 M CaCl₂. (Khamis et al. 2016).

2.1.2. Stock solution of Arghel leaves extract.

Stock solutions of *Arghel* leaves extract were obtained by drying the leaves for 2 h in oven at 70°C and grinding to powdery form; 5 g samples of the powder were refluxed in 100 ml distilled water for 1 h. The refluxed solutions were filtered to remove any contamination. The concentration of the stock solution was determined by evaporating 10 mL of the filtrate and weighing the residue. The concentration of the stock solution was expressed in term of grams per liter.

2.2. Methods.

2.2.1. Electrochemical techniques.

The electrochemical measurements were carried out in a three-electrode mode; platinum sheet and saturated calomel electrodes were used as counter and reference electrodes. The material used for constructing the working electrode was steel that had the following chemical composition (wt%): C, 0.21; S, 0.04; Mn, 2.5; P, 0.04; Si, 0.35; balance Fe.. The steel was encapsulated in epoxy resin in such a way that only one surface was left uncovered. The exposed area (0.785 cm²) was mechanically abraded with a series of emery papers of variable grades, starting with a coarse one and proceeding in steps to the finest (600) grade. The samples were then washed thoroughly with distilled water, followed with A.R. ethanol and finally with distilled water, just before insertion in the cell.

Chronoamperometry and electrochemical impedance measurements were achieved using a GAMRY Instrument (G750).

Chronoamperometry curves were carried out by polarizing the steel electrode to -0.9 V (vs. SCE) in test solution for a total of 20 h. Thus, the current passing through the steel electrode, during calcareous deposits, is recorded with respect to time. The electrochemical impedance spectra (EIS) was made at an open circuit potential in a renewed solution. The frequency range for EIS measurements was 0.1 to 5×10³ Hz with applied potential signal amplitude of 10 mV. Before polarization and EIS measurements, the working electrode was left for 30 min to attain the open

circuit potential in the used solution. (Gabrielli et al. 1996), (Luo et al. 2015), (Garcia et al. 2001), and (Gabrielli et al. 1977).

Polarization curve measurements were by polarizing the working electrode from -250 mV cathodically to +250 mV anodically with respect to open circuit potential at a scan rate of 30 mV/min starting from cathodic potential (E_{corr} -250 mV) going to anodic direction. All the measurements were made at $40.0 \pm 0.1^\circ\text{C}$ in solutions open to the atmosphere under unstirred conditions. To test the reliability and reproducibility of the measurements, duplicate experiments were performed in each case with the same conditions. (Gabrielli et al. 1996), (Luo et al. 2015), (Garcia et al. 2001), and (Gabrielli et al. 1977).

2.2.2. Microscopic examination.

Optical micrographs (40X) were taken with a Euromex optical microscope with color video camera that is connected to a personal computer. (Luo et al. 2015).

Scanning electron microscope examinations were carried out by using (JEOL JSM-5300 Scanning Microscope) with resolution of 10-20 nm, after coating the electrode surface with a golden layer. The magnification at high vacuum mode are 15x to 200,000x and at low vacuum mode are 15x to 50,000x. Acceleration voltage is 0.5 to 30 kV.

3 RESULTS AND DISCUSSION.

3.1. Scale inhibition.

3.1.1. Electrochemical techniques.

i. Chronoamperometry measurement.

The scale is formed in three steps: nucleation, growth, and total coverage of the electrode surface. During the nucleation period, up to 3 h, the scaling process is initialized by increasing the local pH near the electrode surface by the reduction of the dissolved oxygen in solution. The resulting hydroxide ions force few nuclei of CaCO_3 to be born on the electrode. In the growth period, 3–10 h in the scaling environment, the current decreased linearly indicating that the nuclei already born were growing and occupied the surface leaving some parts free. In the total coverage period, more than 10 h, the current reached a limiting value, signifying the scaling time at which total coverage of the electrode surface was obtained. The low limiting current value suggests that the surface coverage is porous, since if it were completely blocked, the current would be zero. Further, cause slight increase in current density.

Figure (1) shows the chronoamperometry curves for polarized steel electrode at 40°C in demineralized water in the absence and the presence of inhibitors:

- In the presence of demineralized water, it was observed that the total surface coverage current increased. This may be attributed to the increase of surface porosity as a result of deformation of the formed crystal. Further, cause slight increase in current density.
- In the presence of 50 ppm *Arghel* and 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) shows that the growth rate that is described by the slope of the line representing the growth step was decreased and the total coverage of the electrode surface within the test period was prevented.

It was found that 50 ppm *Arghel* and 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) prevents both scale growth and total surface coverage stages. Further, cause slight increase in current density.

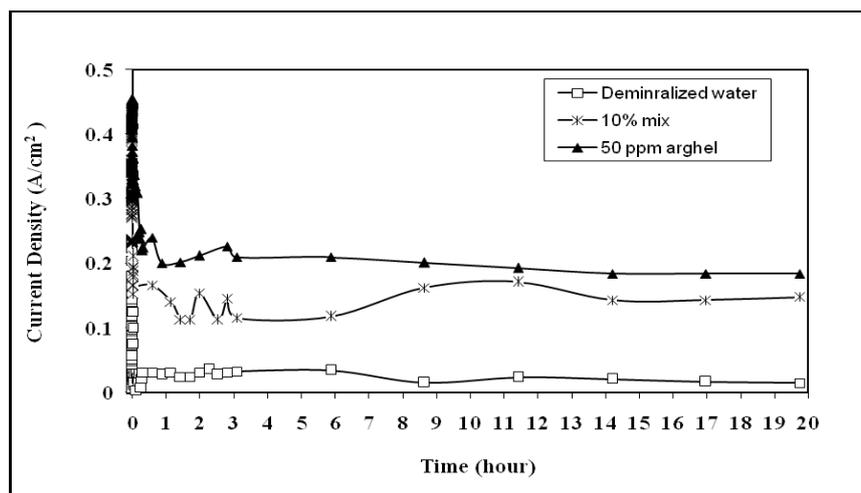


Figure 1. Chronoamperometry curve for polarized steel electrode in demineralized water in the absence and presence of 50 ppm *Arghel* or 10% mix (11.1 mL TSP +11.1 mL Carbohydrazide) at 40 °C.

It can be concluded that the function of 50 ppm *Arghel*, 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) lead to increase the nucleation time, thus, delaying the scale formation.

The inhibition mechanism at the threshold of 50 ppm *Arghel* 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) as scale inhibitor is explained by an adsorption of the inhibitor onto the crystal growth sites of the sub-microscopic crystallites that are initially produced in the supersaturated solution, interfering with crystal growth and altering its morphology. This process can prevent crystal growth or at least delay it for prolonged periods of time.

It is observed that, the variation of current density after polarizing the steel electrode for 20 hour in demineralized water in the absence and the presence of 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm *Arghel* increased, respectively. This means that, the presence of antiscalent impede scale growth; since the current density has inverse relationship to the area covered by the remained nuclei.

ii. Impedance measurements.

Several problems arise for interpreting chronoamperometry curves. First, the dc current gives only partial information on the screening effect of the insulating scale deposit on the electrode surface. (Gabrielli et al. 1977). Second, no information is obtained about the thickness and porosity of the scale layer. (Sule et al. 2013), and (Cruz et al. 2018). The use of impedance technique can improve the understanding of the electrochemical scaling process. (Abd-El-Khalek et al. 2013).

Figure (2) shows Nyquist plots for steel that was cathodically polarized at -0.9 V for 20 h in brine solution, treated water, and in the presence of 50 ppm *Arghel* or 10% mix (11.1 mL TSP +11.1 mL Carbohydrazide). As seen, the figure shows different types of a distorted semicircle. In Calcium Chloride brine solution, the impedance spectrum was related to complete surface coverage stage. Whereas in case of treated water, the spectra was correlated to the stage of growth. On the other hand, on adding 50 ppm *Arghel* or 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide), the spectra were connected to nucleation stage. Therefore, the decrease in the size of the depressed semicircles in the presence of 10% mix (11.1 mL TSP +11.1 mL Carbohydrazide) and 50 ppm of the extracts of *Arghel* leaf respectively is an indication to increasing the scale inhibitive efficiency of the extract and the chemical mix. (Abdel-Gabe et al. 2008), (Abdel-Gaber et al. 2011), and (Senthilmurugan et al. 2011).

Quantitative treatment.

It was reported by (Marin-Cruz et al. 2006) that, due to the irregular form of the impedance spectra at low frequencies, the Warburg type diffusion must be discarded. Some authors have suggested that this irregular shape of the impedance spectra is associated to the presence of simultaneous diffusion of two species (iron ions and oxygen) through the porous surface. (Marin-Cruz et al., 2006), and (Hanan et al. 2014)

Figure (2) shows the equivalent circuit that was earlier proposed by (Belarbi et al. 2014) to fit the experimental data of impedance plots for the scale formation processes, in the circuit R_s represents the solution resistance, R_f is the resistance associated with the layer of products formed during immersion, and R_{ct} corresponds to the charge transfer resistance. CPE_f and CPE_{dl} are the constant phase element corresponds to film and double layer capacitance.

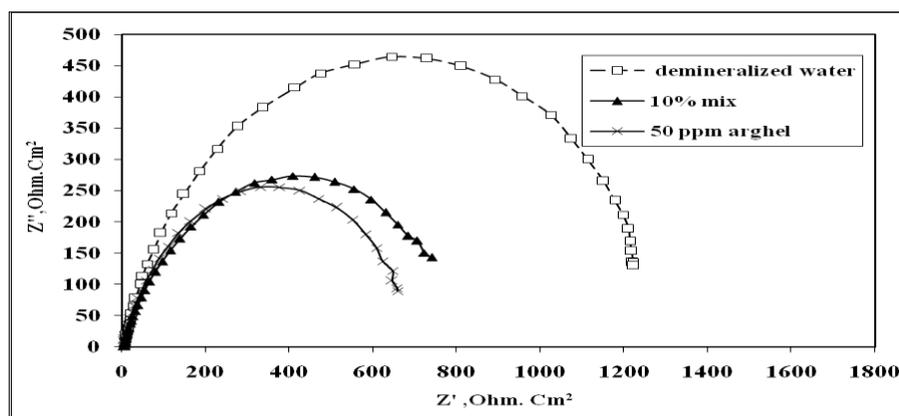


Figure 2. Nyquist plots for polarized steel for 20 h in the CaCl_2 brine solution, in demineralized water in the absence and presence of 50 ppm *Arghel* and 10% mix (TSP+Carbohydrazide).

The change in the film resistance (R_f), charge transfer resistance (R_{ct}), the none ideal film and double layer capacitances in the presence of 50 ppm of *Arghel* leaf extracts and 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide), respectively obtained after 20 hour of polarizing steel electrode at -0.9 V (vs. SCE) are given in Table (1). The data analyzed by Gamry Echem analyst 5.3 software clarify that increasing extract concentrations decreases the charge transfer resistance, film resistance and increases the non-ideal film capacitance confirming the inhibitive effect of the extract towards the scales formation process.

The percentage of scale inhibition can be determined by eq. (1).

$$\% \text{ scale inhibition} = [(R_{ct})_0 - (R_{ct})_i] / (R_{ct})_0 * 100 \quad (1)$$

Where $(R_{ct})_0$ and $(R_{ct})_i$ are the charge transfer resistances in the absence and the presence of scale inhibitor respectively. The percentages of scale inhibition are 60%, and 64% demineralized water in presence of mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm of *Arghel* leaf extracts, respectively related to blank as treated water. On the other hand, the percentage of scale inhibition of demineralized water is 60%, related to Calcium Chloride brine solution. These data are in good agreement with those obtained using chronoamperometry technique.

Table 1. Computer fit results of the impedance spectra obtained at open circuit potential for the steel electrode that was cathodically polarized for 20 h in demineralized water in the absence and presence of mix (TSP+ Carbohydrazide) or 50 ppm *Arghel*.

Solutions	R_f (Ohm.cm^2)	CPE_f (F)	R_{ct} (Ohm.cm^2)	CPE_{dl} (F)	R_s (Ohm.cm^2)
demineralized water	9.022×10^{-12}	273.6×10^{-9}	990	32.23×10^{-6}	29.14
10% Mix (TSP+Carbohydrazid e)	12.13×10^{-12}	318.5×10^{-12}	390	101.4×10^{-6}	6.88
50 ppm <i>Arghel</i>	6.118×10^{-12}	259.6×10^{-12}	350	126.6×10^{-6}	6.21

The data clarify that using 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) and 50 ppm of *Arghel* leaf extracts decreases the charge transfer resistance and film resistance while increases the non-ideal film capacitance. These results confirm the inhibitive effect of *Arghel* and TSP towards scale formation process.

3.1.2. Optical Microscope Examinations.

The optical micrographs of the steel electrode that was polarized at -0.9 V vs. SCE for 20 hour in demineralized water in absence and presence of 50 ppm *Arghel* or 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) are shown in figure (3), respectively. These micrographs display that, in presence of demineralized water, which correlated to the stage of growth, the thickness of scale crystal layer was decreased. The resultant increase in the nucleation time and the accompanied decrease in the growth rate in presence of the antiscalent lead to decrease the amount of the scale deposited over the entire area compared to the uninhibited brine solution. The surface area occupied by the scale particles decreases in presence of 50 ppm *Arghel* or 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) antiscalent extract, respectively. These data are in good agreement with those obtained using chronoamperometry technique.

It is observed that when nucleation period is retarded, few numbers of nuclei were born which begin to grow with starting of growth period leading to large size of crystals in presence of antiscalent, which is fitting with the same results obtained in other different investigations. (Abdel-Gabe et al. 2008) (Abdel-Gaber et al. 2011), and (Elkholy et al. 2018).

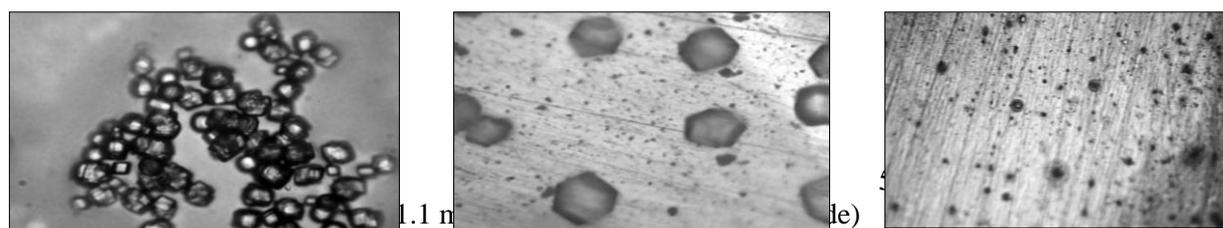


Figure 3. Optical micrograph photo (40×) for cathodically polarized steel after 20 h in the CaCl_2 brine solution and in demineralized water in absence and presence of 10% mix or 50 ppm *Arghel*.

3.1.3. Scanning Electron Microscope Examinations.

Scanning electron microscope (SEM) was used to elucidate the morphology of scale formed on the surface of polarized steel electrode at -0.9 V vs. SCE for 20 hour in the CaCl_2 brine solution in demineralized water in the absence and presence of 50 ppm *Arghel* or 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide). Figures (3) show SEM of non polarized steel electrode.

Figure (4) shows SEM of polarized steel electrode at -0.9 V vs. SCE for 20 hour in demineralized water in absence and presence of 10% mix or 50 ppm *Arghel*, respectively. These micrographs exhibit hexagon, rhombohedron, and two types of crystalline structure that represent: calcite (b, c), and aragonite (d, e).

Considering the results from SEM, the changes of scale shapes resulting from the addition of scale inhibitor show the following characteristics:

- When scale inhibitors do not exhibit high inhibition efficiency, scale shapes are modified to a little extent.
- In the presence of more efficient antiscalent, the precipitated phases are completely different from those produced in blank solution.
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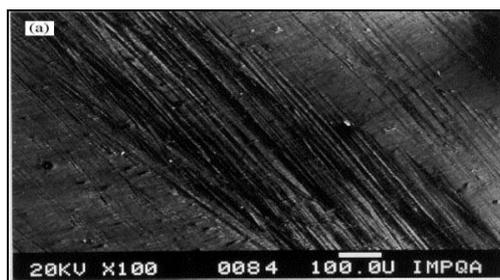


Figure 4. SEM micrographs of non polarized steel electrode.

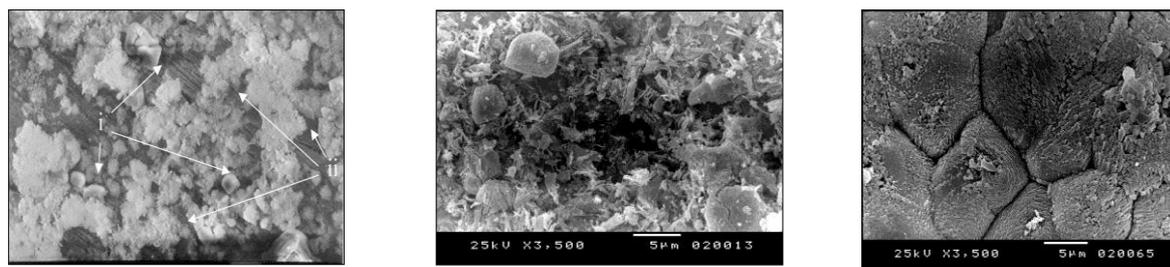


Figure 5. SEM micrographs of polarized steel electrode at -0.9 V vs. SCE for 20 h in demineralized water in absence and presence of inhibitors, i. calcite, ii. Aragonite

3.2. Corrosion inhibition.

3.2.1. Electrochemical Impedance Spectroscopy.

Figure (5) shows Nyquist plots for steel in brine solution and in demineralized water in the absence and presence of 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) and 50 ppm *Arghel*, respectively. The impedance response consists of distorted loop of a capacitive type, whose size increases in 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) than in 50 ppm *Arghel* as an indication to increasing the inhibitive efficiency of the corrosion inhibitors.

The impedance spectra of different impedance (Nyquist) plots were analyzed by Gamry Echem Analyst 5.3 software program. Computer fit results of the impedance spectra obtained in absence and presence of different inhibitors are given in tables (2). The data show that, all solutions have the same behavior; the charge transfer resistance of 50 ppm *Arghel* is lower than 10% mix. Therefore, inhibition efficiency of herb extract is higher than chemical mix used (Abdel-Gaber et al. 2011), and (Kavitha et al. 2011). This can be attributed to the decrease in dielectric constant and/or increase in the thickness of electric double layer, suggesting that the inhibitor molecules act by adsorption mechanism at steel/solution interface.

The percentage of corrosion inhibition ($\% \pi$) can be determined by eq. 2). (Zeng et al. 2012), and (Abd-El-Khalek et al. 2013):

$$\pi\% = \left[1 - \left(\frac{R_{ct}^*}{R_{ct}} \right) \right] \times 100$$

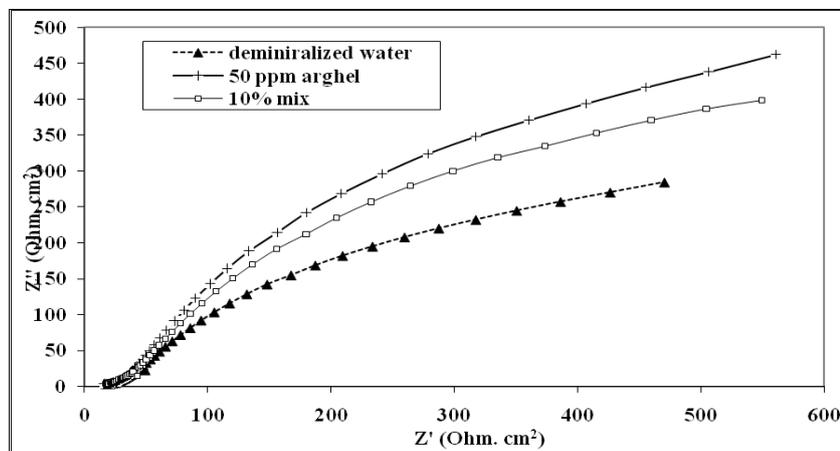


Figure 6. Nyquist plots of steel in brine solution and in demineralized water in the absence and presence of 10% mix or 50 ppm *Arghel*.

Table 2. Computer fit results of the impedance spectra for steel electrode in demineralized water in absence and presence of 10% mix (11.1 mL TSP +11.1 mL Carbohydrazide) and 50 ppm *Arghel*.

Solution	R_s Ohm. cm^2	R_{ct} Ohm. cm^2	$\% \pi$
demineralized water	17.6	471	0
Demineralized water in presence of 10% mix	35.3	561	61
Demineralized water in presence of 50 ppm <i>Arghel</i>	17.8	549	65

Where $\% \pi$, (R_{ct}^*) and (R_{ct}) are percentage of inhibition, the charge transfer resistances without and with the corrosion inhibitor, respectively. The percentages of corrosion inhibition are 61%, and 65% for demineralized water in presence mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm of *Arghel* leaf extracts, respectively related to blank as treated water. On the other hand, the percentage of corrosion inhibition of demineralized water is 26% related to blank as Calcium Chloride brine solution.

These results indicate that chemical mix shows higher corrosion inhibition efficiency than herb extract.

3.2.2. Potentiodynamic Polarization Results.

Figures (6) show the potentiodynamic polarization curves for steel in brine solution and in demineralized water in the absence and presence of 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm *Arghel*, respectively. The figures clarify that addition of the corrosion inhibitor shifts the anodic part of the polarization curves to more noble values and corrosion potential ($E_{corr.}$) into more positive indicating that these inhibitors acts as anodic type inhibitors. (Abdel-Gaber et al. 2011), (Abd-El-Khalek et al. 2013), and (Kumar et al. 2014).

The corrosion current density was calculated from the intersection of cathodic and anodic Tafel line. The Tafel constants, β_a and β_c , were calculated as a slope of the points after corrosion potential by ± 40 mV using a computer software analysis program. The values of the electrochemical parameters for demineralized water in the absence and presence of 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm *Arghel*, in table (3), respectively.

The displayed data show that more decrease in corrosion current density (i_{corr}) by using demineralized water in the absence and presence of 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm *Arghel*, respectively. Moreover, the anodic Tafel slopes (β_a) are approximately constant, while the cathodic Tafel slopes (β_c) have higher numerical values that decrease with increasing extracts concentrations suggesting that the inhibiting action of the extracts takes place by controlling the cathodic processes.

The degree of surface coverage, θ , was calculated by Tafel form, eq (3):

$$\theta = [1 - (i_{corr} / i_{0corr})] \quad (3)$$

Where (i_{corr}) and (i_{0corr}) are the corrosion current densities with and without inhibitor. The percentage of inhibition efficiency ($\% \pi$) was calculated from the degree of surface coverage by eq (4)

$$\% \pi = \theta * 100 \quad (4)$$

or from the polarization measurements using the relation, eq (5) . (Abdel-Gaber et al. 2011), (Kumar et al. 2014), and (Zeng 2012).

$$\% \pi = [1 - (i_{corr} / i_{0corr})] * 100 \quad (5)$$

Where $\% \pi$, i_0 and i are the percentage of inhibition efficiency and the corrosion current density, in absence and presence of herbs extract respectively.

Table (4) shows the variation of the percentage of inhibition for demineralized water in the absence and presence of 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm *Arghel*. Results of the inhibition efficiencies revealed that, the good inhibiting action of 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm *Arghel*. The percentages of corrosion inhibition are 82.4% and 87% for demineralized water in presence mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm of *Arghel* leaf extracts, respectively related to blank as demineralized water. On the other hand, the percentage of corrosion inhibition of demineralized water is 73 % related to blank as Calcium Chloride brine solution, that is fitting with the same results obtained previously [20]. Therefore, 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) shows higher inhibition efficiency than 50 ppm *Arghel* as anticorrosion.

The degree of surface coverage (θ) were found to increase reaching values of 0.82, and 0.87% at mix (11.1 mL TSP + 11.1 mL Carbohydrazide) and 50 ppm of *Arghel* leaf extracts, respectively related to blank as demineralized water. On the other hand, the degree of surface coverage (θ) reached a value of 0.73 at demineralized water.

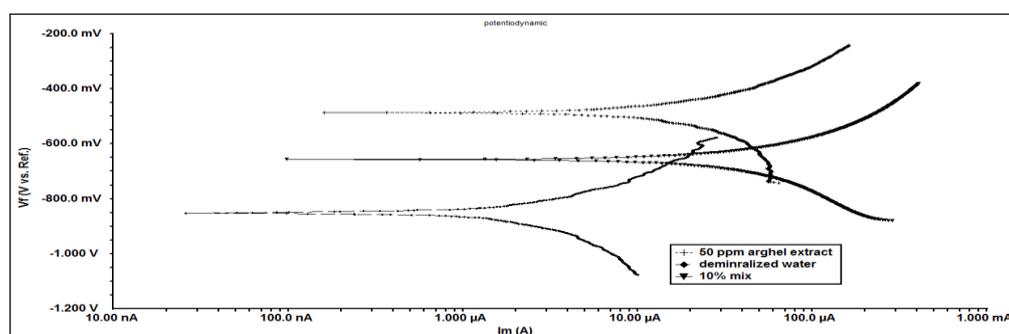


Figure 7. Potentiodynamic polarization curves for steel in brine solution and in demineralized water in the absence and presence of 10% mix or 50 ppm *Arghel*.

Table 3. Electrochemical polarization parameters for steel electrode in demineralized water in absence and presence of 10% mix (11.1 mL TSP + 11.1 mL Carbohydrazide) or 50 ppm *Arghel*.

Solution	β_a (V/decade)	$-\beta_c$ (V/decade)	$I_{corr.}$ (μA)	$-E_{corr.}$ (mV)	Corrosion rate (mpy)
demineralized water	$351.5 e^{-3}$	$7432 e^{-3}$	11.98	554	8.765
Demineralized water in presence of 50 ppm <i>Arghel</i>	$234.1 e^{-3}$	$4464 e^{-3}$	2.1	457	4.82
Demineralized water in presence of 10% mix	$122.4 e^{-3}$	2.103	1.54	427	2.9

Table 4. Percentage of inhibition of polarized steel electrode in demineralized water in absence and presence of 10% mix (11.1 mL TSP + 11.1 mL Elim-OX) or 50 ppm *Arghel*.

Solution	$I_{corr.}$, (μA)	$-E_{corr.}$, (mV)	% π
Demineralized water	11.98	554	00
Demineralized water in presence of 10% mix	2.1	457	82.4
Demineralized water in presence of 50 ppm <i>Arghel</i>	1.54	427	87.1

4 CONCLUSIONS.

This study investigates the possibility for some natural products to act as anti-scalent and anti-corrosion inhibitors in cooling systems used in different industries.

A chemical and physical comparison study between 50 ppm *Arghel* leaf extract and the actually used commercial water treatment chemical mixture of anti-scalent and anti-corrosion that are used to eliminate scale and corrosion was carried out.

The results indicated that, both types of inhibitors, natural and commercial, have a similar effect as cooling water treating agent, but the herb extract was found of dual function effect as anti-scalent and as corrosion inhibitor.

Arghel extract is environmentally friendly inhibitor and has much lower operating cost compared to mixture of TSP and Carbohydrazide that are used commercially in spite of their hazards' effect.

RECOMMENDATIONS.

Few researches are focused on the usage of herb and algal extracts as antiscalent. Further studies are needed to be done in the future to complete this work aiming to replace the widely used unsafe chemical inhibitors by these new environmentally safe substances. The recommended study will cover the following main points:

- Formulating a complete package containing a mixture of herbs (*Arghel* leaves) extracts and examines their synergistic or antagonistic effect.
- Suitable biocide will be added to the package to control the growth of the algae and microorganism and to prolong its active life time.
- Pilot test is needed to examine the efficiency of the prepared complete package in the field and to adjust the required doses needed in industry.
- More interest must be focused on the usage of these extracts in food industries, such as sugar industry, which suffers from sever problem of scaling where chemical antiscalents are prevented.
- Also, It must be focused on the usage of these extracts in open recirculating cooling water systems that reuse cooling water are frequently used at large central utility stations, at chemical, petrochemical, petroleum refining plants, in steel and paper mills, and at all types of processing plants, which suffers from sever problem of scaling.

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