Relation between some Physical and Chemical Parameters Affecting on the Corrosion Rate of Steel from Abu-Qir Till Al-Arish, Egypt During Winter 2008

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Abstract: This paper studied the physico-chemical parameters (pH, salinity, dissolved oxygen, oxidizable organic matter, nutrient salts (NO$_3^-$, NO$_2^-$, PO$_4^{3-}$ and SiO$_2^-$) of 16 surface seawater samples collected from four sectors (Abu-Qir, Damietta, Sahl-El-Tina and Al-Arish) situated along the eastern coastal area of the Mediterranean sea, Egypt during winter 2008. The measurements of the physico-chemical parameters were carried out according to standard methods. The present work also studied, the effect of the measured seawater physico-chemical parameters on the corrosion rates of steel in seawater medium on laboratory scale using weight loss measurements and potentiostat technique. The results revealed that the pH differed from 7.43 and 8.32, while the total alkalinity varied between 2.72 meq/l and 2.975 meq/l. Dissolved oxygen fluctuated between 3.326 ml/l and 7.498 ml/l. Oxidizable organic matter ranged from 0.48 mgO$_2$/l and 3.84 mgO$_2$/l. Phosphate concentration differed between 0.035 µg/l and 0.250 µg/l and silicate concentration fluctuated between 0.002 µg/l and 5.95 µg/l. Nitrite concentration varied between 0.0003 µg/l and 1.25 µg/l and nitrate concentration differed between 0.07 µg/l and 1.36 µg/l. Salinity differed between 38.86% and 50.6%. The corrosion rate of steel varied between 7.609 mpy and 1.576 mpy. The correlation between the physico-chemical parameters and the corrosion rate of steel in the natural collected seawater was:

Corrosion rate of steel = 16.0 + 0.69 pH + 9.14 Alkalinity + 0.039 dissolved oxygen - 0.257 oxidizable organic matter + 4.97 phosphate - 0.10 silicate - 1.65 nitrite + 0.378 nitrate - 0.257 salinity.

Key words: Nutrients • Steel • Potentiostate • Weight Loss • Physico-Chemical Parameters

INTRODUCTION

Environmental Studies: The studied area is located in the eastern part of Alexandria from Abu-Qir till Al-Arish during winter 2008.

Previous environmental studies showed that Abu Qir Bay is a shallow semi-circular basin lying 35 Km east of Alexandria city. The bay has a shoreline of about 50 Km long and the maximum depth of about 16 m. The surface area of the bay is about 360 Km$^2$ and the water volume is 4.3 Km$^3$, Said et al. [1]. The bay was considered as a fertile marine habitat when compared with the other Egyptian Mediterranean coastal waters. As in many coastal regions near major urban areas, the bay is used for variety of purposes: commercial fishing, shipping, recreational boating, swimming and as a repository for sewage effluents, Howaida [2]. During the last three decades, the bay is facing the problem of pollution which discharges into the bay from different sources; El-Tabia Pumping Station (TPS), the outlet of Edku Lake and the Rosetta mouth of the Nile River. The estimated amount of untreated sewage and industrial wastes from 22 different factories pumped to Abu Qir Bay through TPS is of about 2 millions m$^3$/day. The exchange of water between Abu Qir Bay and Edku Lake occurring through El-Maadiya channel (about 100m long, 20m wide and 3m deep) is controlled by the prevailing wind and the difference in water level between the Bay and the Lake. Actually, the amount of brackish water discharged from the Lake to the bay is at the rate of 3.3 million m$^3$/discharge/day, Amin et al. [3]. Damietta Branch receives a large amount of effluents of mostly untreated agricultural domestic and partially treated industrial wastewater, Zydah [4]. Some studies have been published on the physico-chemical characters of the River Nile. Shaaban et al. [5] and Abdo [6] studied the physical and chemical characters of the River Nile at Damietta branch. The Damietta Branch receives nutrients and organic loads, as a result of discharges from the Tellhia fertilizer industry and agricultural drains especially near the Faraskour Dam. The drainage at Meet Al-Kholei village also receives sewage water that population residing in this area

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Corrosion Studies: Seawater is recognized to be one of the most corrosive electrolytes under natural environment. The seawater with approximately 3.5% salinity is used by many industries such as shipping, offshore oil and gas production, power plants and coastal industrial plants. The main use of seawater is for cooling purposes but it is also used for fire-fighting, oil field water injection and for desalination plants, Sridhar et al. [8], Vukovic [9], Oh et al. [10] and Bonnel et al. [11]. The local corrosion behaviors of low alloy steels in seawater are extremely complex because numerous factors, such as metallurgical, geometrical and environmental, will together contribute to this corrosion process, Issaeling [12]. Azzam et al. [13] studies carried out an assessment on corrosion rate of steel in seawater by polarization resistance technique. The study showed that electrochemical data are in good agreement with weight loss measurements throughout four years of immersion in natural seawater and give information about the corrosion mechanisms.

The corrosion rate of metal in seawater depends on how rapidly oxygen diffuses to metal surface. When corrosion is controlled by diffusion of dissolved oxygen, the rate of corrosion becomes sensitive to the prevailing hydrodynamic conditions i.e. relative motion between the solution and the corroding surface. The higher these motions are the higher the rate of corrosion owing to the increase of oxygen supply, Nigel [14].

The short term immersion corrosion of mild and low alloy steels in seawaters is known to be proportional to the concentration of dissolved oxygen (DO) in the bulk water. Longer-term corrosion is a function of the activity of sulphates-reducing bacteria and is influenced by the concentration of nutrients in the bulk water, Melchers [15].

In addition to the salt (NaCl) in seawater there are other commonly occurring constituents, dissolved gases, living organisms and various other materials found in seawater. Temperature, dissolved oxygen and pollutants are some examples of issues that may affect the corrosion of a given component in seawater. Alkali metal salts (KCl, LiCl, NaCl, SO4, NaI, NaBr, etc.) affect the corrosion rate of iron and steel in approximately the same manner as sodium chloride. Nitrites appear to be slightly less corrosive than chlorides or sulphates at low concentration, Nigel [14].

There are also biological factors which are bacterial settlement have a depolarizing effect on oxygen reduction at seawater temperatures < 40°C. At these temperatures, the oxygen reduction rate on specimens covered by bacterial slim reaches its steady value within 4 to 5 days after cathodic potential is applied. These results can explain how the corrosion rate of stainless steels in natural seawater decreases when the temperature increases over 40°C, Mollica [16].

This study aims to study the corrosion rate of steel in seawater medium on laboratory scale using weight loss measurement and potentiostat technique. It aims also to study the effect of different seawater physico-chemical parameters; pH, total alkalinity, salinity %s, dissolved oxygen, oxidizable organic matter and nutrient salts (nitrite, nitrate, phosphate and silicate) from Abu-Qir till Al-Arish during winter season 2008 on the corrosion rate of steel and find a relation between these parameters and the corrosion rate of steel in seawater medium.

MATERIALS AND METHODS

Surface seawater samples were collected from Abu-Qir, Damietta, Sahl-El-Tina and Al-Arish sectors, Egypt (Figure 1) during winter season 2008.

Samples Collection: Water samples were collected from four sectors (Abu-Qir (5 stations), Damietta (4 stations), Sahl-El-Tina (4 stations) and Al-Arish (3 stations)) during winter 2008. Surface seawater samples were collected in prewashed polyethylene bottles (2L) using Neskin Reversing bottle. Geographic Positional System was used to adjust the longitude and latitude of each sample. All samples were filtered before measuring all parameters.
Fig. 1: Sample collections from Abu-Qir, Damietta, Sahl-El-Tina and Al-Arish sectors during winter 2008.

Physical Parameters Measurements of Seawater
Salinity (S%): Salinity was measured using Salinometer model Beckman RS-10-X3.

Chemical Parameters Measurements of Seawater
Hydrogen-ion Concentration (pH): The pH-value of water samples were measured to about 0.1 units in situ by using a portable pH-meter (Orion Research model 210 digital pH-meters) after necessary precautions in sampling and standardization processes.

Dissolved Oxygen (DO): DO was determined according to the classical Winkler’s method modified by Grasshoff [17]. The amount of dissolved oxygen in each sample was calculated by applying the following equation:

\[ O_2 \text{ ml/l} = \frac{(N \times V \times 320000/4)/(B - 2) \times 1.43}{\text{ml of sample}} \]

N = Normality of sodium thiosulphate
V = Volume of sodium thiosulphate
B = Volume of oxygen bottle

Alkalinity: The total alkalinity is determined according to Standard Methods [18]. Alkalinity is calculated from the following equation:

\[ \frac{\text{ml of HCl} \times 1000 \times N_{\text{HCl}}}{\text{Total alkalinity (meq/l)}} = \frac{\text{ml of sample}}{V} \]

Nutrient Salts: The most important salts are determined which are the dissolved inorganic forms of nitrogen (NO₃⁻ and NO₂⁻), phosphate (PO₄³⁻) and silicate (SiO₄²⁻). They were determined colorimetrically according to the methods described by Parsons [20] and their absorbance’s were measured by using a Double-Beam spectrophotometer model Shimadzu UV-150-02. The values were expressed as μmol/l.

Chemical Composition of Steel: The used steel had the following chemical composition (wt. %): C, 0.288; Mn, 0.578; P, 0.0698; S, 0.0121; other constituents, 0.1621, Fe, 98.89 (balance Fe).

Weight Loss Measurements: Sheets of steel with thickness of 0.4 mm were cut to panel dimensions 5.8 x 3 x 0.4 cm with a tiny hole at the top. The edges were tabard and their surfaces were polished with a series of emery papers starting with a coarse one and proceeding in steps to finer grades down to 800 grade emery paper, cleaned in acetone rinsed with distilled water, dried, weighed and stored in a moisture-free desiccators prior to use. Each panel was immersed in bottle 1 L glass containing 1L of filtered seawater collected from the surface seawaters samples of the mentioned sectors just after measuring the different physical and chemical parameters of the seawater. After 24 hour the panels were removed and the corrosion products on the specimen surfaces were removed chemically by immersion in a specific solution (500 ml HCl + 500 ml distilled water + 3.5 g hexamethylenetetramine) that was vigorously stirred for 10 min at 25°C, Yuanai et al. [21] and International standard ISO 9226 [22]. After removal of corrosion products, the specimens were rinsed with distilled water, dried in warm air and then weighed to determine their mass loss.
Polarization Measurements: Polarization measurements were performed with potentiostat Wenking MP 87 at a 15 mV/min scan rate. All electrochemical tests were performed with conventional three-electrode configuration: a Pt rod as counter electrode, saturated calomel electrode (SCE), as reference electrode and the constructed steel with chemical composition mentioned above as working electrode. The steel was covered with epoxy resin to leave an exposed area of 2 cm². The exposed area was mechanically polished with a series of emery papers of variable grades, starting with a coarse one and proceeding in steps to the finest (800) grade. The specimens were then washed thoroughly with double distilled water, followed with A.R. ethanol and finally with distilled water, just before insertion in the cell. Tafel slopes (βa and βc) were calculated as a slope of the points after corrosion potential (Ecorr) by ±50mV using a computer software program. The corrosion current densities are obtained by extrapolation of the anodic and cathodic Tafel lines to the corresponding corrosion potential. All electrochemical experiments were repeated two times to test the reproducibility of the measurements.

RESULTS AND DISCUSSION

Physico-Chemical Parameters from Abu-Qir till Al-Arish During Winter 2008: From Table (1); it is noticed that pH differed from (7.43) at station 4 Al-Arish sector and (8.32) at station 3 Sahil-El-Tina sector. Total alkalinity varied between (2.72) meq/l at station 4 Al-Arish sector and (2.975) meq/l at station 1 Sahil-El-Tina sector. Dissolved oxygen differed between (3.326) ml/l at station 4 Sahil-El-Tina sector and (7.498) ml/l at station 4 Damietta sector. Oxidizable organic matter varied between (0.48) mgO₂/l at station 4 Damietta sector (accompanied with highest dissolved oxygen concentration) and (3.84) mg O₂/l at station 3 Damietta sector. Phosphate concentration differed between (0.035) μg/l at station 4 Sahil-El-Tina sector and (0.25) μg/l at station 3 Damietta sector. Silicate concentration fluctuated between (0.002) μg/l at station 3 Abu-Qir sector and (5.95) μg/l at station 5 Abu-Qir sector. Nitrite concentration varied between (0.0003) μg/l at station 5 Sahil-El-Tina sector and (1.25) μg/l at station 1 Abu-Qir sector. Nitrate concentration differed between (0.07) μg/l at station 4 Al-Arish sector and (1.36) μg/l at station 5 Damietta sector. Salinity differed between (38.8 %) at station 5 Abu-Qir sector and (50.6 %) at station 4 Sahil-El-Tina sector.

Relation Between Corrosion Rate of Steel and Physico-Chemical Parameters During Winter 2008: Table 2 shows the electrochemical parameters of steel in seawater in different stations of studied sectors from Abu Qir till Al-Arish during the year of 2008. The parameters include the corrosion potential (Ecorr), anodic and cathodic tafel slope (βa and βc), the corrosion current density (i corr) and the corrosion rate (mpy).

The corrosion potential ranged from 666 mV for station 3 in Al-Arish sectors to 740 mV for station 1 in Damietta sector. However, the corrosion current density fluctuated between (0.0034) mA/cm² to (0.0167) mA/cm² in Sahil-El-Tina sector for stations 4 and 1, respectively.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>Alkalinity (meq/l)</th>
<th>Dissolved oxygen ml/l</th>
<th>Oxidizable organic matter (mgO₂/l)</th>
<th>PO₄²⁻- (μg/l)</th>
<th>SIO₃⁻- %</th>
<th>NO₃⁻- mpy</th>
<th>NO₂⁻</th>
<th>Salinity %</th>
<th>Corrosion Rate*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abu-Qir 1</td>
<td>7.82</td>
<td>2.933</td>
<td>6.146</td>
<td>2.880</td>
<td>0.100</td>
<td>1.369</td>
<td>1.2500</td>
<td>0.994</td>
<td>39.000</td>
<td>4.096</td>
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<td>Abu-Qir 2</td>
<td>7.76</td>
<td>2.805</td>
<td>6.377</td>
<td>1.920</td>
<td>0.050</td>
<td>1.131</td>
<td>0.375</td>
<td>0.645</td>
<td>39.100</td>
<td>4.594</td>
</tr>
<tr>
<td>Abu-Qir 3</td>
<td>7.96</td>
<td>2.805</td>
<td>6.430</td>
<td>1.760</td>
<td>0.100</td>
<td>0.002</td>
<td>0.350</td>
<td>0.330</td>
<td>39.000</td>
<td>4.936</td>
</tr>
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<td>Abu-Qir 5</td>
<td>7.93</td>
<td>2.805</td>
<td>5.920</td>
<td>1.280</td>
<td>0.100</td>
<td>5.950</td>
<td>1.0000</td>
<td>0.715</td>
<td>38.800</td>
<td>4.169</td>
</tr>
<tr>
<td>Abu-Qir 6</td>
<td>7.86</td>
<td>2.805</td>
<td>6.677</td>
<td>0.950</td>
<td>0.100</td>
<td>0.774</td>
<td>0.1250</td>
<td>0.657</td>
<td>38.890</td>
<td>5.999</td>
</tr>
<tr>
<td>Damietta 1</td>
<td>8.17</td>
<td>2.890</td>
<td>5.008</td>
<td>1.440</td>
<td>0.100</td>
<td>3.154</td>
<td>0.1000</td>
<td>0.172</td>
<td>40.300</td>
<td>5.269</td>
</tr>
<tr>
<td>Damietta 3</td>
<td>7.98</td>
<td>2.763</td>
<td>4.107</td>
<td>3.840</td>
<td>0.250</td>
<td>2.797</td>
<td>0.1500</td>
<td>0.598</td>
<td>40.500</td>
<td>3.998</td>
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<tr>
<td>Damietta 4</td>
<td>7.56</td>
<td>2.805</td>
<td>7.498</td>
<td>0.480</td>
<td>0.100</td>
<td>3.392</td>
<td>0.0250</td>
<td>0.349</td>
<td>40.500</td>
<td>5.269</td>
</tr>
<tr>
<td>Damietta 5</td>
<td>7.47</td>
<td>2.890</td>
<td>6.378</td>
<td>2.880</td>
<td>0.050</td>
<td>3.332</td>
<td>0.0004</td>
<td>1.366</td>
<td>40.300</td>
<td>5.465</td>
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<td>Sahil-El-Tina 1</td>
<td>8.16</td>
<td>2.975</td>
<td>4.319</td>
<td>2.880</td>
<td>0.100</td>
<td>1.845</td>
<td>0.0250</td>
<td>0.621</td>
<td>40.000</td>
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<td>Sahil-El-Tina 3</td>
<td>8.32</td>
<td>2.805</td>
<td>3.641</td>
<td>1.750</td>
<td>0.050</td>
<td>2.142</td>
<td>0.1300</td>
<td>1.264</td>
<td>40.400</td>
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<td>8.31</td>
<td>2.805</td>
<td>3.326</td>
<td>1.120</td>
<td>0.035</td>
<td>2.023</td>
<td>0.0250</td>
<td>1.320</td>
<td>50.600</td>
<td>1.576</td>
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<td>Sahil-El-Tina 5</td>
<td>8.26</td>
<td>2.763</td>
<td>4.089</td>
<td>1.440</td>
<td>0.050</td>
<td>2.737</td>
<td>0.0003</td>
<td>0.476</td>
<td>49.300</td>
<td>3.643</td>
</tr>
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<td>Al-Arish 1</td>
<td>7.56</td>
<td>2.933</td>
<td>5.257</td>
<td>1.600</td>
<td>0.050</td>
<td>3.392</td>
<td>0.1000</td>
<td>0.342</td>
<td>40.100</td>
<td>4.367</td>
</tr>
<tr>
<td>Al-Arish 3</td>
<td>8.28</td>
<td>2.763</td>
<td>6.604</td>
<td>1.440</td>
<td>0.050</td>
<td>3.213</td>
<td>0.0750</td>
<td>0.367</td>
<td>40.000</td>
<td>3.506</td>
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<td>Al-Arish 4</td>
<td>7.43</td>
<td>2.720</td>
<td>5.010</td>
<td>1.280</td>
<td>0.100</td>
<td>2.440</td>
<td>0.1000</td>
<td>0.070</td>
<td>40.400</td>
<td>3.734</td>
</tr>
</tbody>
</table>

Corrosion rate*: the corrosion rate from weight loss measurements.
During winter 2008, the corrosion rate of the four sections (Abu-Qir, Sahl-El-Tina, Damieta and Al-Arish) were measured by weight loss measurement (Table 1) and their values varied between a minimum of (1.576) mpy at station 4 Sahl-El-Tina sector accompanied with lowest PO$_4^{3-}$-concentration (0.035) µg/l and a maximum of (7.609) mpy at station 1 Sahl-El-Tina sector accompanied with highest alkalinity (2.975) meq/l and relatively high value of oxidizable organic matter (2.880) mgO$_2$/l.

According to Abu-Qir sector, corrosion rate increased gradually with increasing dissolved oxygen concentration along the stations (1, 2 and 3) being (4.096, 4.594 and 4.938) mpy respectively, while at Abu-Qir 5, its corrosion rate decreased to (4.169) mpy accompanied by lowest DO concentration (5.92) mll, salinity (38.8%) and highest silicate concentration (5.950) µg/l then increased again to (5.999) mpy at Abu-Qir 6. The lowest corrosion rate (4.096) mpy at Abu-Qir 1 was accompanied with
highest alkalinity value (2.933) meq/l, oxidizable organic matter concentration (2.88) mgO₂/l, nitrite concentration (1.25) µg/l and nitrate concentration (0.125) µg/l, while the highest corrosion rate (5.999) mpy at Abu-Qir 6 was accompanied with the highest dissolved oxygen concentration (6.677) ml/l and lowest oxidizable organic matter concentration (0.960) mgO₂/l and nitrite concentration (0.125) µg/l. Figure (2) showed that silicate, nitrite and nitrate concentrations were inversely correlated with corrosion current density (i_corr) while DO concentration is directly correlated with corrosion current density (i_corr) in Abu-Qir during winter 2008.

The potentiodynamic polarization curves for steel in seawater collected from stations (1, 2, 3, 5 and 6) of Abu-Qir sector (Figure 3) showed that all stations were in parallel correlation except Abu-Qir 1 station which showed shift of anodic polarization curve to more noble direction which mean a decrease in the rate of anodic reaction which may be due to the highest values of nitrite and nitrate concentrations as mentioned above.

In Damietta sector, it was noticed that the corrosion rate in most stations varied between (5.206 mpy-5.465 mpy) except station 3 at Damietta sector which showed the lowest corrosion rate 3.998 mpy due to the relatively lowest cathodic and anodic corrosion rate, that may be due to the lowest dissolved oxygen concentration (4.107) ml/l and highest phosphate concentration (0.25) µg/l and nitrates concentration (0.0004) µg/l. Station 5, Damietta sector showed the highest corrosion rate (5.465) mpy accompanied with highest alkalinity and nitrate and
Fig. 4: Dissolved Oxygen (DO), Oxidizable Organic Matter (OOM) and Corrosion current density \( i_{corr} \) of steel in seawater of Damietta sector during winter 2008.

Fig. 5: Corrosion current density \( i_{corr} \) of steel in seawater of Sahl-El-Tina sector (a) Dissolved Oxygen (DO), (b) Phosphate Concentration and (c) Nitrate Concentration during winter 2008.

lowest pH, phosphate and nitrite concentrations. Figure (4) showed that corrosion current density \( i_{corr} \) was directly correlated with dissolved oxygen and inversely correlated with oxidizable organic matter in Damietta sector during winter 2008.

The potentiodynamic polarization curves for steel in seawater collected from stations (1, 3, 4 and 5) of Damietta sector (Figure 3) showed that all stations were in parallel correlation except Damietta 3 station which showed the lowest corrosion rate (3.998) mpy due to relatively lowest cathodic and anodic corrosion rate that may be due to the lowest dissolved oxygen concentration and highest phosphate and silicate concentrations.

In Sahl-El-Tina sector; the corrosion rate varied between a minimum of (1.576) mpy and a maximum of (7.609) mpy. The lowest corrosion rate (1.576) mpy at station 4 Sahl-El-Tina sector was accompanied with lowest dissolved oxygen (3.326) ml/l, oxidizable organic matter concentration (1.120) mgO₂/l and phosphate concentration (0.035) µg/l and highest nitrate concentration (1.320) µg/l while the highest corrosion rate (7.609) mpy at Sahl-El-Tina 1 is accompanied with highest alkalinity (2.975) meq/l, dissolved oxygen (4.319) ml/l, oxidizable organic matter concentration (2.88) mgO₂/l and phosphate concentration (0.100) µg/l and lowest silicate concentration (1.845) µg/l and salinity (40 %). Figure (5) showed that corrosion current density \( i_{corr} \) was inversely
Fig. 6: Potentiodynamic polarization curves for steel in seawater collected from Abu-Qir sector, Damietta sector, Sahl-El-Tina sector and Al-Arish sector in (a) station 1, (b) station 3, (c) station 4 and (d) station 5.

correlated with nitrate concentration while the corrosion current density \( (i_{corr}) \) was correlated with dissolved oxygen and phosphate concentration in Sahl-El-Tina sector during winter 2008.

The potentiodynamic polarization curves for steel in seawater collected from stations (1, 3, 4 and 5) of Sahl-El-Tina sector (Figure 3) showed that all stations were in parallel correlation except Sahl-El-Tina 4 station which showed the lowest corrosion rate (1.576 mpy) which is due to the lowest anodic corrosion reaction that may be due to highest nitrate concentration and lowest phosphate, dissolved oxygen and oxidizable organic matter concentrations.

At Al-Arish sector, corrosion rate varied in small ranges between (3.506 mpy and (4.367 mpy). The lowest corrosion rate value (3.506 mpy) at Al-Arish 3 was accompanied with lowest nitrite (0.0750) mg/l and salinity (40 %) and highest pH (8.28), dissolved oxygen (2.763) ml/l and nitrate concentration (0.367) mg/l while the highest corrosion rate (4.367) mpy at Al-Arish 1 was accompanied with highest alkalinity (2.933) mcq/l, oxidizable organic matter concentration (1.6) mgO2/l, silicate concentration (3.392) µg/l and nitrite concentration (0.1) µg/l. The potentiodynamic polarization curves for steel in seawater collected from stations (1, 3 and 4) of Al-Arish sector (Figure 3) showed that all stations were in parallel correlation except Al-Arish 3 station which showed the lowest corrosion rate (3.506) mpy and anodic corrosion rate that may be due to the highest nitrate concentration and lowest salinity value.

The potentiodynamic polarization curves for steel in seawater of station 1 for Abu-Qir, Sahl-El-Tina, Damietta and Al-Arish sectors during winter 2008 (Figure 6) showed that all stations were in parallel correlation except Abu-Qir 1 station which showed the lowest corrosion rate (4.096) mpy and anodic corrosion rate that may be interpreted by the highest nitrite and nitrate concentrations and lowest salinity value for Abu-Qir 1 station.
The potentiodynamic polarization curves for steel in seawater of station 3 for Abu-Qir, Sahl-El-Tina, Damietta and Al-Arish sectors during winter 2008 (Figure 6) showed that all stations were in parallel correlation except Al-Arish 3 station which showed the lowest corrosion rate (3.506) mpy that can be discussed due to highest silicate concentration and lowest oxidizable organic matter concentration at Al-Arish 3 station.

The potentiodynamic polarization curves for steel in seawater of station 4 for Sahl-El-Tina, Damietta and Al-Arish sectors during winter 2008 (Figure 6) showed that all stations were in parallel correlation except Sahl-El-Tina 4 station which showed the lowest corrosion rate (1.576) mpy that was accompanied with highest pH, nitrate concentration and lowest dissolved oxygen concentration at Sahl-El-Tina 4 station.

The potentiodynamic polarization curves for steel in seawater of station 5 for Abu-Qir, Sahl-El-Tina and Damietta sectors during winter 2008 (Figure 6) showed that all stations were in parallel correlation.

As shown from Table 2, the results obtained showed that the corrosion current density (i cor) and the corresponding calculated corrosion rate (mpy) from weight loss measurements (Table 1) were in agreement with each other. In addition all the anodic Tafel slope (βa) values were slightly changed except the value of station 4 for Sahl El-Tina sector that recorded 118mV/Decade (Table 2). This may be attributed to the effect of physical and chemical parameters which were similar in anodic corrosion process. On the other hand the cathodic Tafel slope showed changes in some stations that may due to the different concentration of oxygen reduction.

From the correlation between the corrosion rate and the physico-chemical parameters (Table 3); it was found that the corrosion rate is positively correlated with alkalinity (0.5109) while it is negatively correlated with salinity (0.59178), n=16, p<0.05.

From Table 3, the regression equation according to the correlation between the physico-chemical parameters and the corrosion rate of steel was found to be:

- Corrosion rate of steel = -16.6 +0.69 pH + 9.14 Alkalinity +0.039 Dissolved oxygen-0.257 Oxidizable Organic Matter +4.97 Phosphate concentration-0.10 Silicate concentration-1.65 Nitrate concentration +0.378 Nitrate concentration-0.257 Salinity

The stepwise regression response to corrosion rate on 9 predictors with n=16 (Table 4) showed that the corrosion rate of steel is highly correlated with S % followed by alkalinity value and then NO3 as follows:

<table>
<thead>
<tr>
<th>pH</th>
<th>Alk.</th>
<th>DO</th>
<th>OOM</th>
<th>PO4^3-</th>
<th>SiO3^2-</th>
<th>NO3^-</th>
<th>NO2^-</th>
<th>S%</th>
<th>Corr. rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>-0.088</td>
<td>1.000</td>
<td>-0.547</td>
<td>0.017</td>
<td>1.000</td>
<td>-0.000</td>
<td>0.357</td>
<td>-0.248</td>
<td>1.000</td>
</tr>
<tr>
<td>-0.091</td>
<td>-0.136</td>
<td>-0.053</td>
<td>-0.209</td>
<td>1.000</td>
<td>-0.095</td>
<td>0.189</td>
<td>0.262</td>
<td>0.137</td>
<td>0.093</td>
</tr>
<tr>
<td>-0.092</td>
<td>-0.027</td>
<td>-0.014</td>
<td>-0.132</td>
<td>0.023</td>
<td>1.000</td>
<td>-0.095</td>
<td>0.212</td>
<td>-0.264</td>
<td>0.301</td>
</tr>
<tr>
<td>0.439</td>
<td>-0.240</td>
<td>-0.596</td>
<td>-0.215</td>
<td>-0.313</td>
<td>0.015</td>
<td>-0.357</td>
<td>0.253</td>
<td>1.000</td>
<td>-0.097</td>
</tr>
<tr>
<td>Corr. rate</td>
<td>0.144</td>
<td>0.511</td>
<td>0.251</td>
<td>0.211</td>
<td>0.139</td>
<td>-0.169</td>
<td>-0.118</td>
<td>-0.097</td>
<td>-0.592</td>
</tr>
</tbody>
</table>

Correlation Matrix (n=16, p<0.05); without (underlined) bold are significant

<table>
<thead>
<tr>
<th>Step</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>13.676</td>
<td>-7.841</td>
<td>-7.712</td>
</tr>
<tr>
<td>S%</td>
<td>-0.221</td>
<td>-0.186</td>
<td>-0.239</td>
</tr>
<tr>
<td>T-Value</td>
<td>-2.750</td>
<td>-2.450</td>
<td>-3.450</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.016</td>
<td>0.029</td>
<td>0.005</td>
</tr>
<tr>
<td>Alk.</td>
<td>7.100</td>
<td>8.000</td>
<td></td>
</tr>
<tr>
<td>T-Value</td>
<td>1.930</td>
<td>2.490</td>
<td></td>
</tr>
<tr>
<td>P-Value</td>
<td>0.076</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>-1.550</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-Value</td>
<td>-2.340</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-Value</td>
<td>6.037</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>1.10</td>
<td>1.61</td>
<td>0.908</td>
</tr>
<tr>
<td>R-Sq</td>
<td>0.502</td>
<td>0.494</td>
<td>0.654</td>
</tr>
</tbody>
</table>

Corrosion rate of steel =-13.676-0.221 S%
Corrosion rate of steel =-7.841-0.186 S%+7.100 Alkalinity
Corrosion rate of steel =-7.712-2.340 S%+8.000 Alkalinity-1.55 NO3
CONCLUSION

- The corrosion rate of steel in seawater medium collected from Abu-Qir, Damietta, Sahl-El-Tina and Al-Arish during winter 2008 on laboratory scale satisfies the regression equation:
  Corrosion rate of steel = -16.0 +0.69 pH + 9.14
  Alkalinity + 0.039 dissolved oxygen - 0.257 oxidizable
  organic matter + 4.97 phosphate - 0.10 silicate - 1.65
  nitrite + 0.378 nitrate - 0.257 salinity.

- Generally, the lowest corrosion rates of steel in seawater medium collected from the eastern part of Egypt extended from Abu-Qir till Al-Arish during winter 2008 were directly proportional with the lowest dissolved oxygen concentration values while the highest corrosion rates values of steel were directly proportional with the highest alkalinity and dissolved oxygen concentrations.

- The results of the corrosion current density \(i_{corr}\) measured using potentiostat technique and the corresponding calculated corrosion rate \(mpy\) measured by weight loss technique agreed with each other.

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REFERENCES


