INVESTIGATION OF PIPELINES' FAILURE PROBLEM OF ELSHABAB PUMPING STATIONS

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ABSTRACT

The east Delta horizontal expansion reclamation project is one of the Egyptian reclamation projects which was implemented in 1981. The project area is approximately equal to 366,500 Feddans. It's located in Ismalia Governorate at kilo 96.5 Cairo-Ismalia road. The irrigation system in this project depends on pumping stations at the right bank of Ismalia Canal through pipelines. The pipelines were subjected to failure problems at different positions. This paper studies the causes of this failure and the different factors affecting them. Technical data including the material of pipelines and operating conditions were collected. Water and soil samples were extracted from the studying area where a complete analysis was performed. This research concluded that, water table, soil resistivity, chlorides contents, electrical conductivity, potential drop, pH, TDS, calcium carbonates and non homogeneity of the soil increase the corrosion rate. Also, the electro-magnetic field produced from the presence of medium and high voltage transmission lines, the improper installation of some parts of the pipelines and the adverse environmental conditions are the main factors which speed up the corrosion rate. This paper recommended that, a good drainage system should be carried out to reduce the water table, replacing and upgrading the pipelines and installing cathodic protection system to overcome the failure problem. A protection and monitoring system was designed for safety and reliability of the project.

Keywords: Pipelines – Corrosion – Cathodic protection.

1. INTODUCTION

The east delta horizontal expansion area is divided into 13 areas as shown in Figure (1). El-Salheia and Shabab area is irrigated by a pipeline system. This system faced a big problem which is the failure of the irrigation pipelines at different positions. This failure is very dangerous because it breaks down the irrigation system which may lead to destroying the whole project. This paper studies the problem of the pipelines' destruction.

It concentrates on the factors that affect the failure and how to change the conditions of these factors to overcome this problem. In addition, a protection and monitoring system is designed to protect and monitor the irrigation pipelines. The study consists of three main parts. The first part is the field measurements and soil and water sampling. The second part is a laboratory work to analyze the samples. The third part includes discussion and analysis of the results. A conclusion for the whole work was carried out.

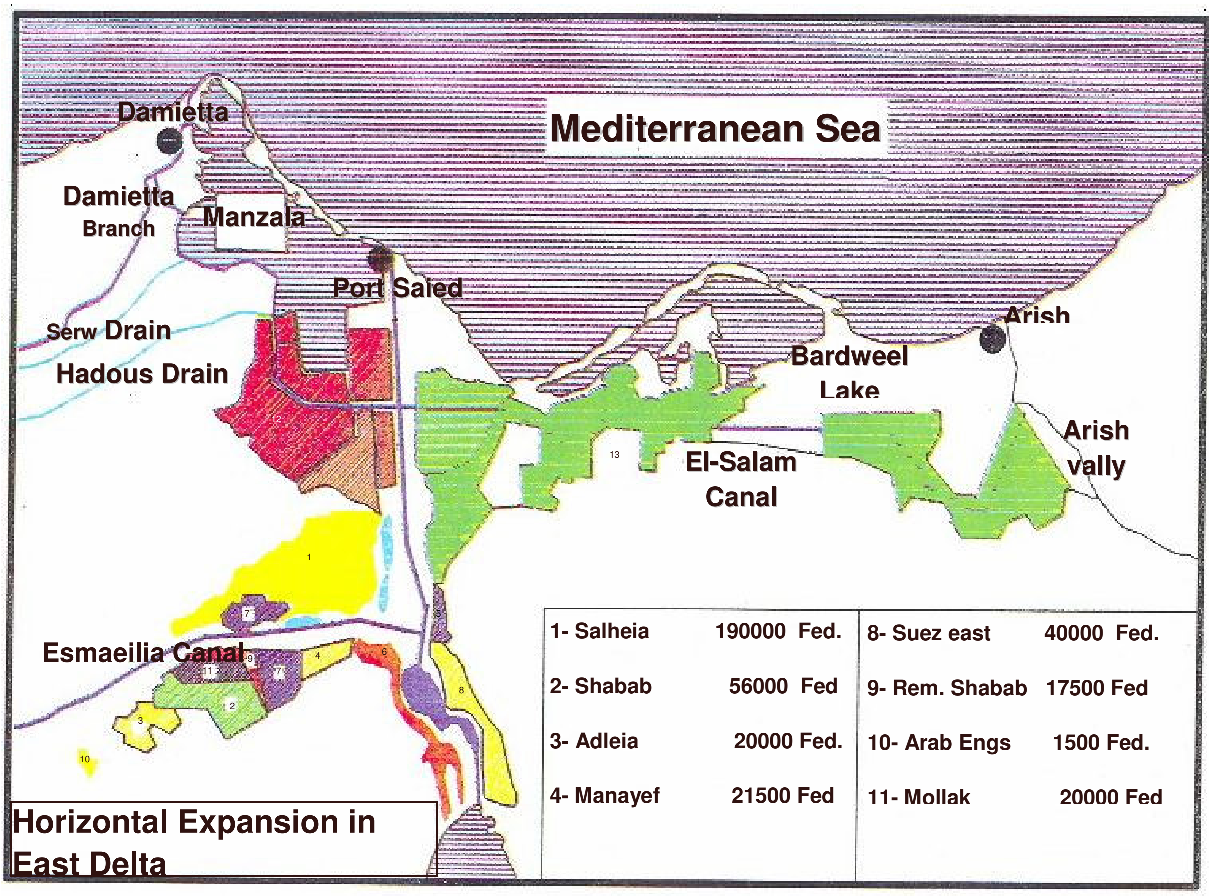


Fig. 1 Horizontal Expansion in East Delta

2. METHODOLOGY

2-1- Description of the Piping System

The pipelines were installed in 1981. The total length of the pipeline is 15,592 meters and its diameter is 1.5 meters. The length and material of each pipeline connection are shown in Figure 2. The studying area is only between El-Shabab pumping stations number 1 and 2. The pipelines in the studying area include four parts. The first part is a pre-stressed concrete pipeline (PSCP) which has 1,500 meters length, the second part is a cast iron pipeline which has 553 meters length, the third part is a pre-stressed concrete pipeline (PSCP) which has 3,500 meters length, and the fourth part is a cast iron pipeline which has 2,708 meters length. The third part is the most infected one and it suffers from severe corrosion and failure at different positions. The total thickness of the (PSCP) is 18 centimeters consisting of 4 millimeter thickness steel pipe covered by a 6 centimeters concrete layer; in addition the steel bars net which is covered by another layer of concrete 10 centimeters thick.

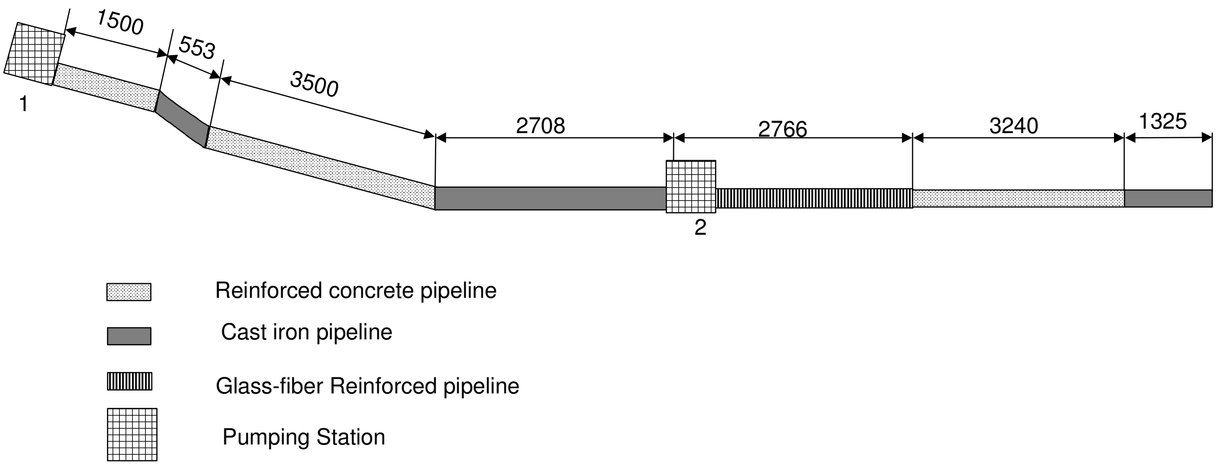


Fig. 2 Total pipeline parts

2.2. Field Inspection and measurements

1- Different parts of the pipelines were visually inspected, where the failure problem was found mostly in the third part.
2- Thickness measurements were carried out of the damaged parts.
3- Potential measurements were carried out at different positions near and far from the damaged parts.
4- pH measurements were carried out at different positions near and far from the damaged parts.

Figures 3 and 4 show parts of a corroded pipeline. Figure 5 shows iron bars inside part of a corroded pipe. Figure 6 shows an iron bar which is supposed to be inside the pipeline. The pipeline was destroyed in this part and the pre-stressed concrete bar was found above the ground surface. Figure 7 shows part of a corroded pipe.

Fig. 3 Part of a corroded pipe

Fig. 4 Part of a corroded pipe

Fig. 5 Iron bars inside pipeline

Fig. 6 Iron bar on the ground surface

Fig. 7 Part of a corroded pipe

2.3. Soil Sampling

Thirty-nine soil samples were extracted from different locations as follows:

1- Three soil samples were collected from the first location which was 10 meters apart from the bridge carries the pipelines in the area of the third pipeline connection.
2- Four soil samples were collected from the second location which was 300 meters apart from the first location.
3- Five soil samples were collected from the third location which was 700 meters apart from the second location.
4- Three soil samples were collected from the fourth location which was 150 meters apart from the third location.
5- Four soil samples were collected from the fifth location which was 200 meters apart from the fourth location.
6- Four soil samples were collected from the sixth location which was 550 meters apart from the fifth location.
7- Four soil samples were collected from the seventh location which was 1400 meters apart from the sixth location.
8- Three soil samples were collected from an open hole next to the first location.
9- A soil sample was collected from an open hole next to the second location.

10- Four soil samples were collected from an open hole next to the third location.
11- Four soil samples were collected from an open hole next to the fourth location.

2.4. Water Sampling

Three water samples were extracted from different locations as follows:

1- A water sample from the first location.
2- A water sample from the second location.
3- A water sample from the water refiner which was in the mid distance between pumping stations one and two.

2.5. Experimental Work and Analysis

Chemical analysis including Chlorides, Sulfides, and Calcium carbonates were performed. Acidity and alkalinity (pH), total dissolved salts (TDS) contents, Electrical conductivity (E_c) and electrical resistivity were measured for the thirty nine soil samples and the three water samples.

3. RESULTS, ANALYSIS AND DISCUSSION

3.1. The acidity and alkalinity (pH) measurements

The measurements of the acidity and alkalinity pH are shown in Figures 8 and 9. Their values were between 7.3 – 8.6. These values mean that the soil is quite alkaline. This leads to increasing the corrosion rate. The maximum values of pH were at about 1200 meters from the bridge carrying pipes and at a depth of about 6 meters.

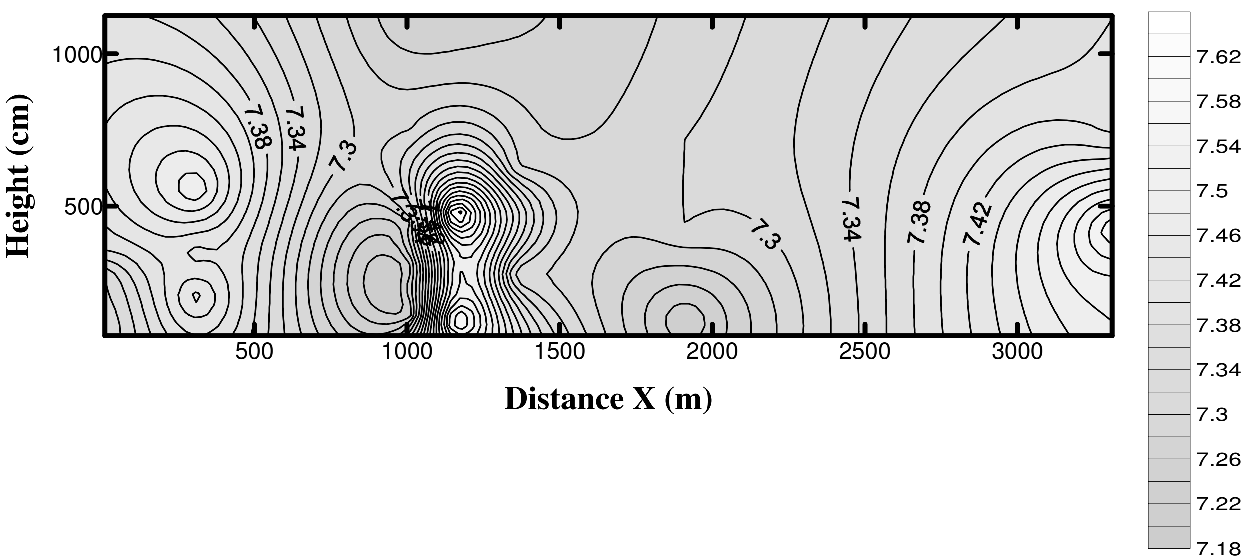


Fig. 8 pH Distribution

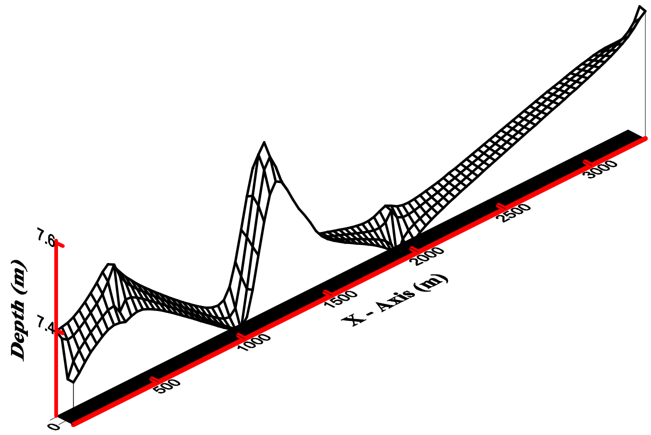


Fig. 9 pH Distribution

3.2. The Potential Distribution

Most metals are made from natural compounds called ores. These ores contain metals that are combined with oxygen or sulfur. Metals are formed when ores are heated to remove oxygen and sulfur. Metals store this heat as chemical potential energy during the refining process. Metals corrode when they release stored energy through electrochemical reactions. Electrochemical reactions involve the transformation of chemical energy into electrical energy.

Figure 10 shows the refining and corrosion cycle for a common iron ore called hematite (Fe_2O_3). Hematite changes into iron when energy is added during the refining process. Carbon and other alloys such as Si, Mn, …, etc are added during the alloying process to convert iron into steel. The steel releases the stored energy when it changes to rust, Fe_2O_3 during the corrosion process. Notice that hematite and rust have the same composition (Fe_2O_3).

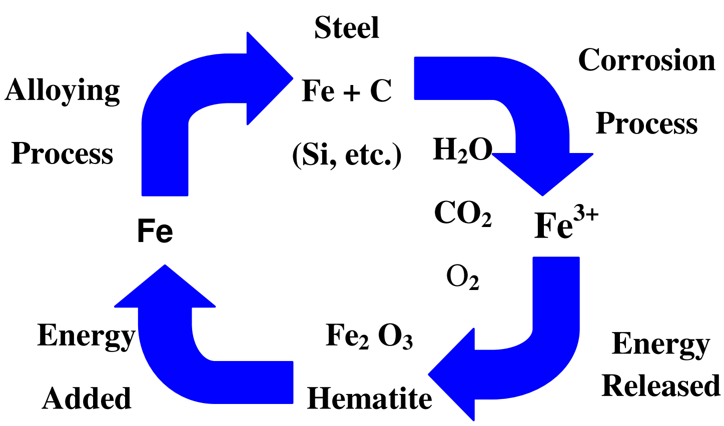


Fig. 10 The iron cycle in nature

3.3. The Soil Potential IR

The values of potential measurements in different locations of soil were ranging between 0.6 - 0.65 volts. To be safe from corrosion, the value of the potential shouldn't be less than 0.85 volts. But the measuring values were between 0.6 and 0.65 volts, so the pipeline was in the corrosive environment. The steel in concrete was subjected to corrosion mechanism. Rust was formed in the steel bars, it expanded, the concrete began to crack. The expansion of steel bars was continued until the outer concrete were completely destroyed [4].

3.4. The Soil Electric Conductivity E_c

The measurements of the electrical conductivity are as shown in Figure 11 and their values are ranging between 0.2 to 2.8. The values lead to an increase in the corrosion rate.

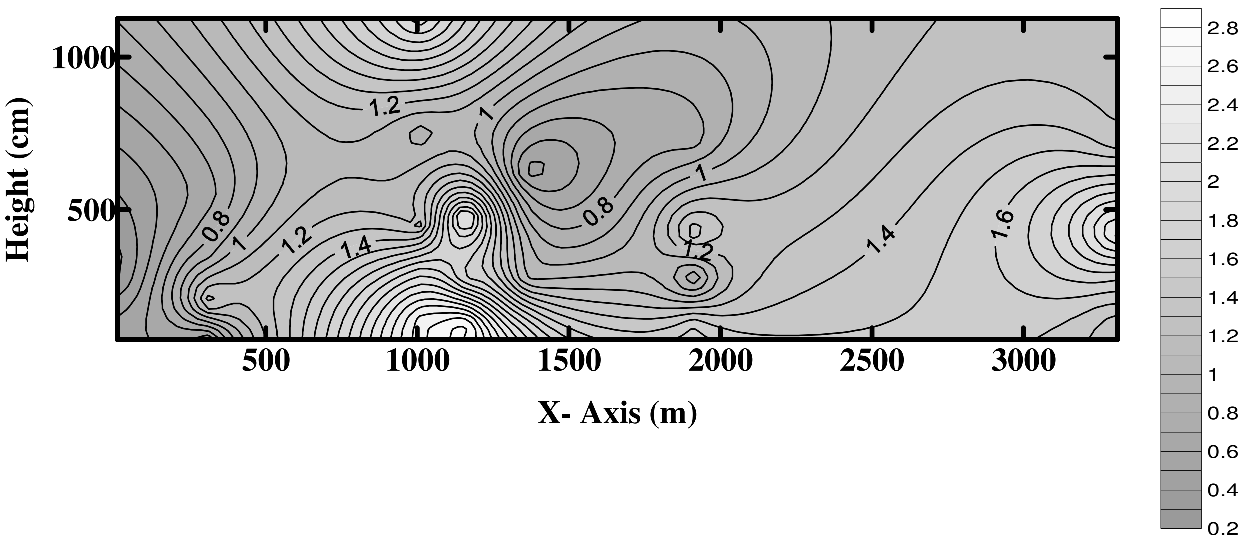


Fig. 11 Electrical Conductivity Distribution

3.5. The Soil Electric Resistivity E_R

The measurements of the soil resistivity are as shown Figure 12 and their values are ranging between 0.2 to 3.8. According to Figure 13 which indicates the relation between the soil resistivity and the corrosion rate [9], the soil resistivity values are found in the extremely corrosive zone. The low values of soil resistivity increase the corrosion rate rapidly.

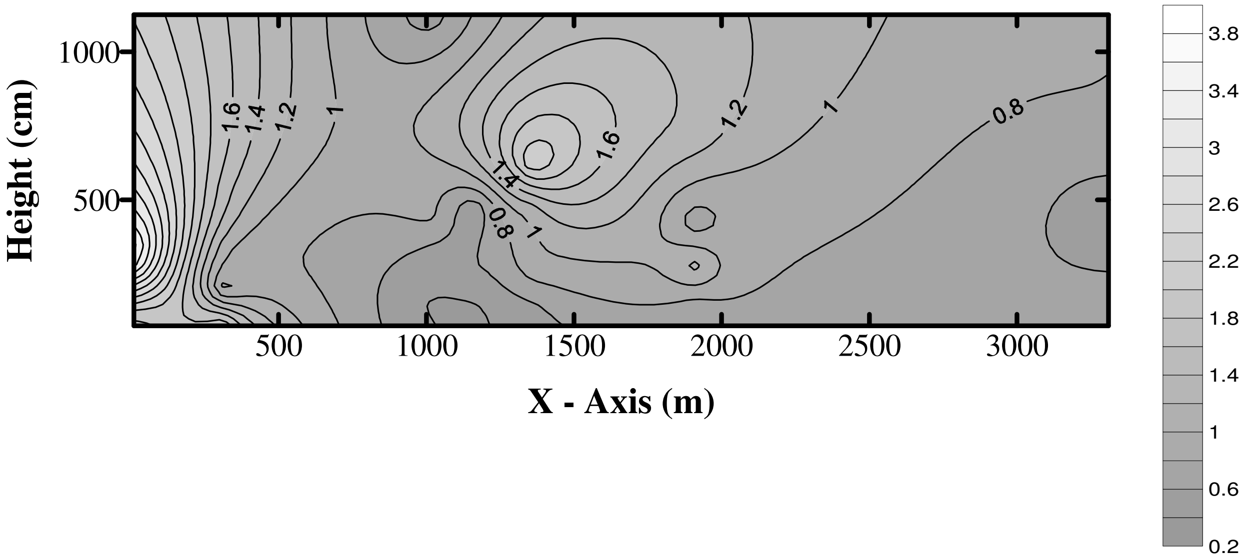


Fig. 12 Electrical Resistivity Distribution

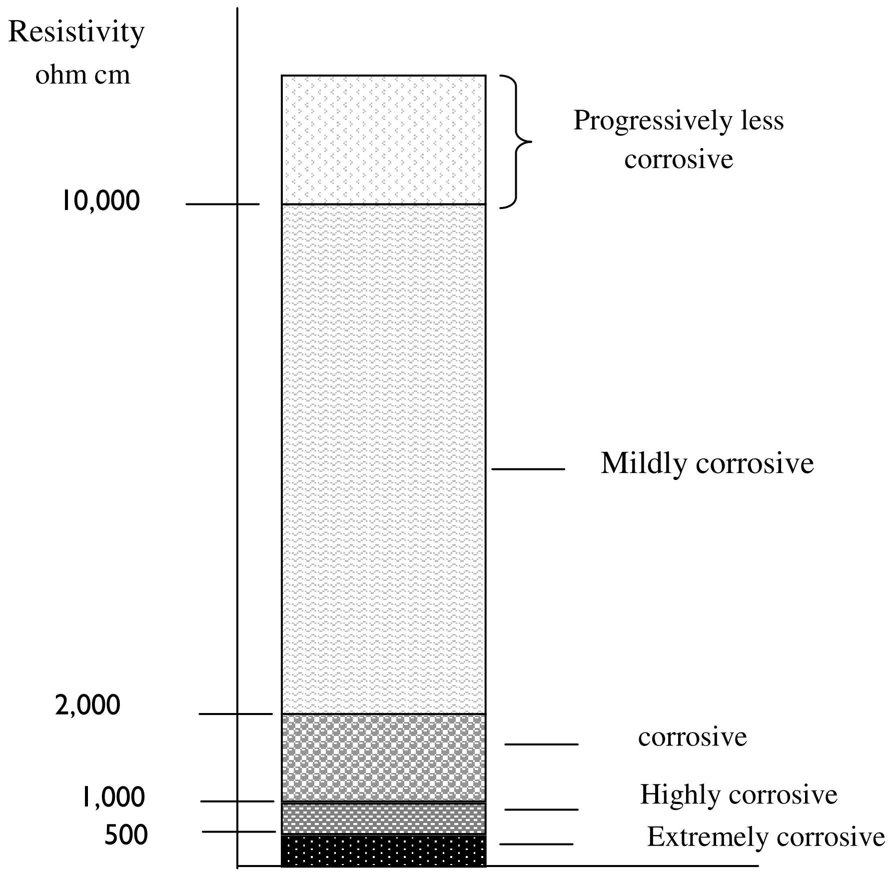


Fig. 13 Relation between soil resistivity and corrosion rate

3.6. Water Table

Because there is no drainage system in this area, the ground water increased to a very dangerous level. In some locations, it reached the ground surface and the pipelines were submersed in water which leads to the following:

1- Increasing the soil conductivity.
2- Decreasing the soil resistivity.
3- Increasing the soluble salts.
4- Increasing the corrosion rate

The first three factors lead to increase the corrosion rate rapidly. Also, the increase in water table affected directly the corrosion rate and indirectly by increasing conductivity and soluble salts contents and by decreasing the resistivity.

3.7. Aeration in Soil

Due to the non-homogeneity of soil and non-homogeneity of pipeline buried, and to sandy soil, an aeration system was found leading to increasing the corrosion rate.

3.8. Presence of Power Transmission Lines

In addition to all the previous conditions, there are power transmission lines in this area. These transmission lines as shown in Figure 14 produce electro-magnetic field which in turn increase the corrosion rate. The value of the electro-magnetic field depends on the distance from the transmission line. The pipelines exist in the affected area [8].

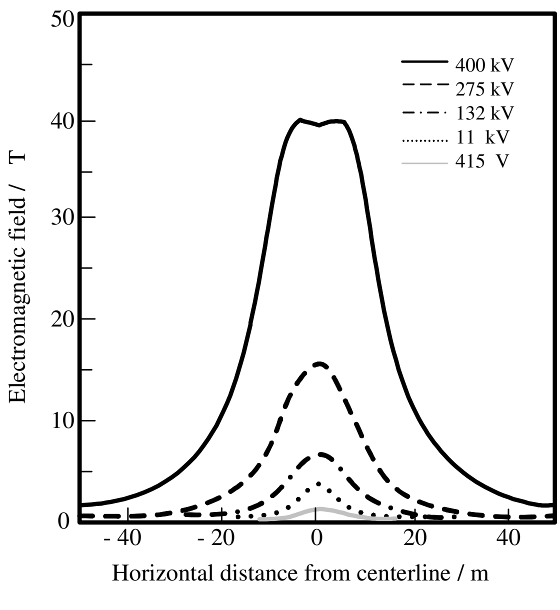


Fig. 14 Relation between electromagnetic field and the distance

3.9. Chlorides in Soil

According to Figure 15, the Chlorides' values rang between 27 to 210 ppm. This amount of chlorides causes an increase in the corrosion rate.

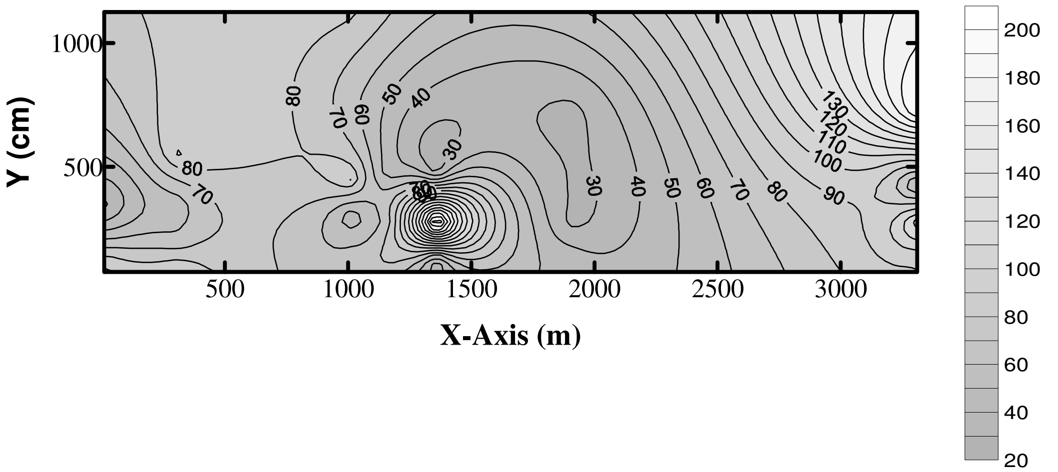


Fig. 15 Cloride Distribution

3.10. Sulfides in Soil

According to Figure 16, the amount of sulfides ranges between 30 to 930 ppm. This amount of sulfides causes an increase in the corrosion rate.

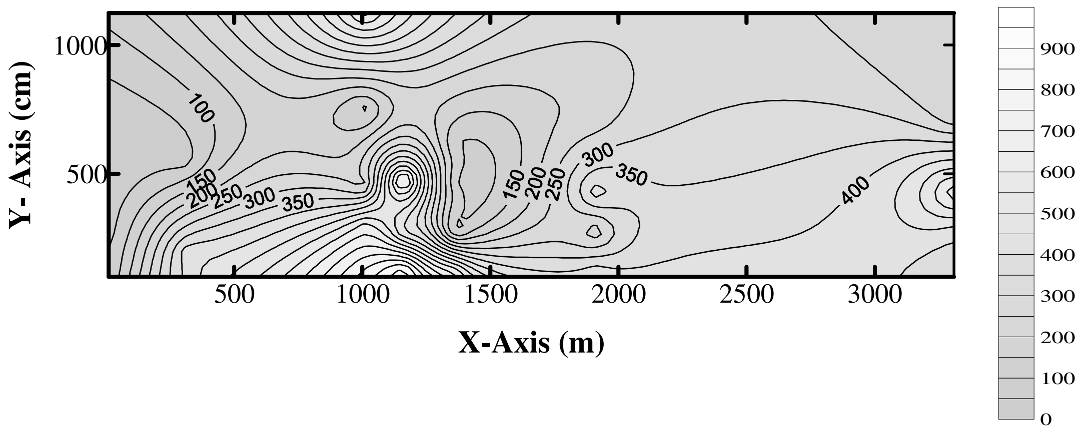


Fig. 16 Sulfide Distribution

3.11. Total Dissolved Salts (TDS) in Soil

According to Figure 17, the amount of the total dissolved salts TDS ranges between 175 to 1760 ppm. This amount of dissolved salts leads to decrease in the soil resistivity which causes an increase in the corrosion rate. Also dissolved salts increase the soil conductivity.

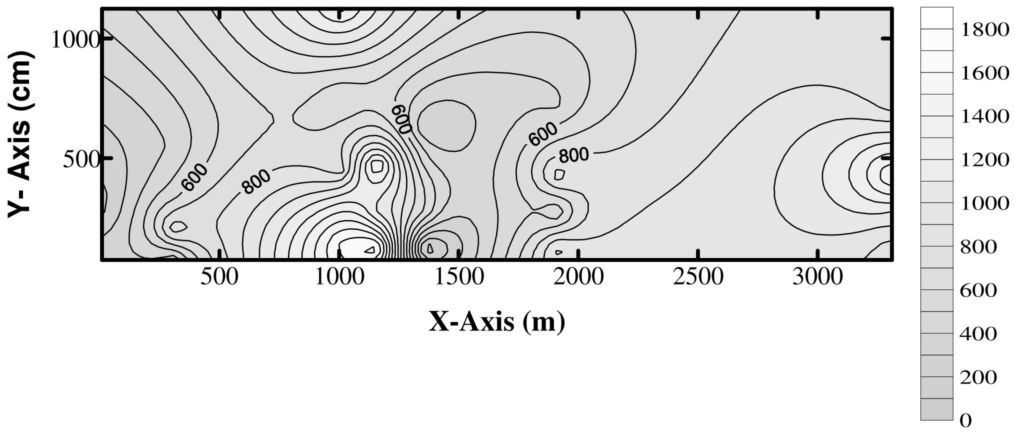


Fig. 17 TDS Distribution

3.12. Calcium Carbonates in Soil

According to Figure 19, calcium carbonates are found in 20 soil samples from 39. Calcium carbonates leads to increase the corrosion rate rabidly.

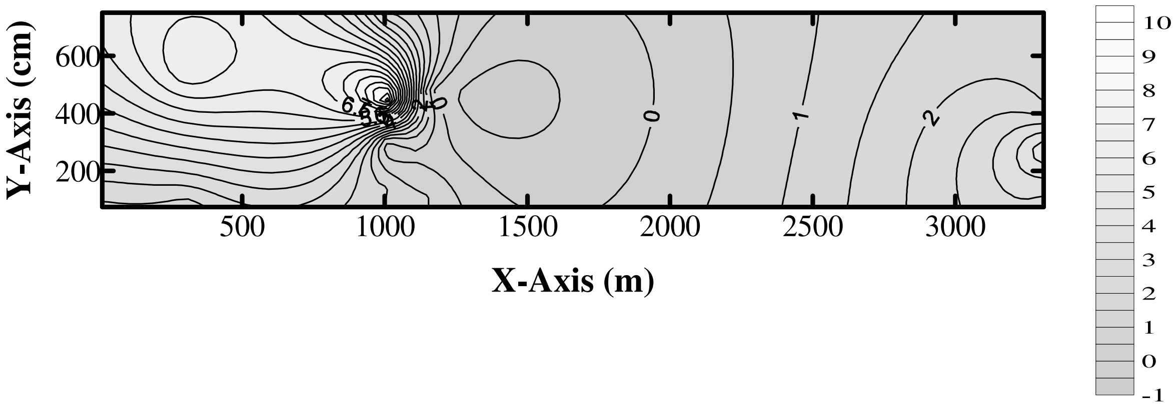


Fig. 18 Calcium Carbonates Distribution

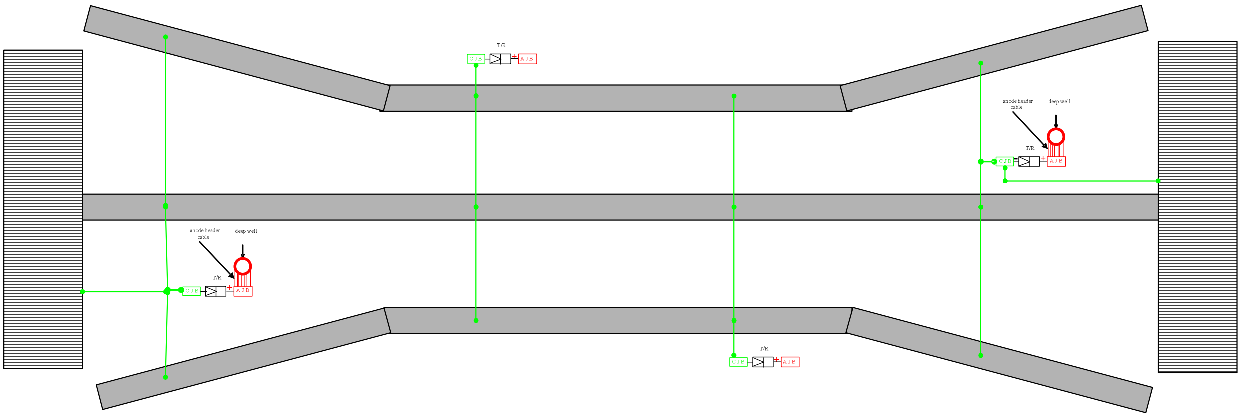
3.13. Replacement of the damaged Parts

When failure happened in some parts of the pipelines, the damaged old parts were replaced by new ones which were connected with the old pipelines. Potential difference between the new parts and the old parts in the pipelines is produced. This potential causes the corrosion mechanism [1].

Design a Protection and Monitoring System

By analyzing the results of the chemical analysis and the measurements of soil potential, electric conductivity, electric resistivity, and pH, it was found that; it is very important to construct a protection and monitoring system to overcome all these effects and to stop the corrosion process [2].

Before implemented the cathodic protection system, a drainage system should be carried out first to remove the ground water where the pipelines are submerged.



The surface area of the pipeline in the distance between T_1 and T_2 =

$$A1 + A2 + A3 + A4 = 116727.93 \ m^2 \quad (1)$$

Total current required to protect the first four pipes = 973.82344 A

Select high silicon cast iron anode of diameter = 7.62 cm
and length = 152.4 cm

No. of anodes based on the anode max. current density [6]

$$N = \frac{A}{\pi D L \gamma}$$

$$N = 268 \text{ Anodes} \quad (2)$$

No. of anodes based on the anode consumption rate [7]

$$N = \frac{Y \times A \times \gamma}{\omega}$$

$$N = 263 \text{ Anodes} \quad (3)$$

For design purposes use the more conservative value N = 268 anode (50 kg wt.)

Twenty high silicon iron anodes 1.52 meters long, spaced on 2.5 meters centers are used in each deep well. Standards require at least 6 meters of coke breeze above the anodes and a minimum of 1.55 meters below the anodes. The minimum length of this particular coke breeze column is 45 m.

The anode bed can be considered as a single anode we can calculate the deep anode bed resistance using Dwight equation as follows:

$$R_v = \frac{0.159\rho}{L}\left(\ln\frac{8L}{D} - 1\right)$$

$$R_v = 1.4214971\ \Omega \tag{4}$$

The total circuit resistance is taken = 1.6 Ω.

The current output of an impressed current system is a function of the DC power source deriving voltage and the circuit resistance. The current output A of a deep anode impressed current system is given by the following formula:

$$E_D = I\ R_c = 389.52938\ \text{Volts} \tag{5}$$

The nearest standard for transformer rectifier units is 1000 A DC / 500 V DC
Take 4 transformer rectifier units from the nearest standard.

Deep Wells:

A minimum distance (75 m) is required between a deep anode bed and the pipeline. Four deep wells each 120 m deep, 31 cm diameter are used.

4. CONCLUSION AND RECOMMENDATION

4.1. CONCLUSION

According to the field study, experimental and theoretical analysis, there are some factors that increase the rate of corrosion of the pipelines. Increasing the corrosion rate leads to the failure of the pipeline. These factors can be concluded as follows:

1- Increasing water table, due to the fact that there is no drainage system in this area, the ground water increased to a very dangerous level, reaching the ground surface in some locations. In the studying area, the pipelines were submersed in water increased the soil conductivity, the soluble salts contents and the corrosion rate and decreased the soil resistivity.
2- Decreasing soil resistivity E_R. The measurements of the soil resistivity were between 0.2 and 3.8. These low values of soil resistivity increase the corrosion rate rapidly.
3- Increasing soil conductivity Ec. The measurements of the electrical conductivity were between 0.2 and 2.8. The values increase the corrosion rate [3].

4- The soil potential IR. The values of potential measurements in different locations of soil were between 0.6 and 0.65 volts. These values are lower than the corrosion critical limit (0.85 volts) [5]. So, the steel in concrete was subjected to the corrosion mechanism. Rust was formed in the steel bars, expanded in the concrete which began to crack. The expansion of steel bars was continued until the outer concrete of the pipelines was destroyed.
5- The soil alkalinity. The measurements of pH were between 7.3 and 8.6. These values mean that the soil is quite alkaline. This lead to an increase in the corrosion rate.
6- Increasing Oxygen contents. Due to the non-homogeneity of soil and non-homogeneity of pipeline buried, and to sandy soil, an aeration system was found leading to an increase in the corrosion rate.
7- Increasing total dissolved salts (TDS) in soil. The amount of the total dissolved salts TDS was between 175 and 1760 ppm. This amount decreased the soil resistivity which causes an increase in the corrosion rate. Also dissolved salts increase the soil conductivity.
8- Increasing Chlorides in soil. The Chlorides contents were between 27 and 210 ppm. This amount of chlorides caused increasing in the corrosion rate.
9- Increasing Sulfides in soil. The amount of sulfides was between 30 and 930 ppm. This amount caused an increase in the corrosion rate.
10- Presence of calcium carbonates. Calcium carbonates were found in 20 soil samples from the 39 samples. The presence of calcium carbonates in soil led to a rapid increase in the corrosion rate.
11- Presence of medium and high voltage transmission lines. These transmission lines produce electro- magnetic field which in turn increase the corrosion rate.
12- The presence of new and old parts of the pipelines due to the replaced parts because of the failure. Potential difference between the new parts and the old parts in the pipelines was produced. This potential caused a corrosion mechanism which increased the corrosion rate.
13- Some parts in the pipelines which are buried near the ground surface were destroyed due to passing heavy trucks over them.

4.2. RECOMMENDATIONS

1- A good drainage system should be carried out in the area to decrease the water table.
2- The corroded parts of the pipelines should be replaced.
3- The designed protection and monitoring system should be implemented to monitor and protect the pipelines and to overcome the failure problem.
4- The pipeline should be protected with a mish of metallic bond under the medium and high voltage transmission lines.

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