



## **Corrosion Behavior in External Surface of API 5L X52 Underground Pipelines in Buzurgan Region/ Missan province**

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### **Abstract**

External corrosion of underground pipeline is one of the most common damage mechanisms associated with the soil environment particularly in ageing pipelines. This study investigates the external corrosion phenomenon for exporting crude oil pipeline (28") in Buzurgan region / Missan province. Corrosion rate was measured by using weight loss method, and Tafel extrapolation. Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were also used in this work. During the field survey, soil sample was taken from Buzurgan region (collected as close as possible to buried pipes at 1.2 m) for tests were carried out for soil that included: pH, moisture content, resistivity and chemical composition (XRF, XRD, and soluble salts). It was found that the environment of the areahas a low soil resistivity value (870) ohm.cm. On other hand, the samples that were immersed in Buzurgan soil showed the that highest damage was by pitting corrosion due to the high soluble salts content particularly chlorides (7388 )ppm and sulfates (2570) ppm.

**Keywords:** Buried pipe, corrosion, chemical composition for soil, API 5L X52.

## سلوك التآكل في السطح الخارجي لخطوط لخط أنابيب API 5L X52 في منطقة البزركان / محافظة

ميسان

### الخلاصة:

يعد التآكل الخارجي لخطوط الأنابيب تحت الأرض، من احد آليات الضرر الأكثر شيوعًا المرتبطة ببيئة التربة، خاصة في خطوط الأنابيب القديمة. تبحث هذه الدراسة في ظاهرة التآكل الخارجي لخط أنابيب تصدير النفط الخام (28 بوصة) في منطقة البزركان /محافظة ميسان. تم قياس معدل التآكل بطريقة فقدان الوزن وكذلك طريقة استقراء تافل. أيضاً، في هذا العمل، تم استخدام المجهر الإلكتروني الماسح (SEM)، والتحليل الطيفي المشتت للطاقة (EDS). خلال المسح الميداني، تم أخذ عينة من التربة من منطقة البزركان (تم جمعها في أقرب نقطة من الأنابيب المدفونة عند 1.2 م) لإجراء اختبارات على التربة التي شملت: درجة الحموضة pH، ومحتوى الرطوبة، والمقاومة والتركيب الكيميائي (XRF ، XRD، و الأملاح القابلة للذوبان). من النتائج التجريبية، يمكن أن نستنتج أن بيئة المنطقة قيد الدراسة تعتبر اكلة للغاية؛ حيث ان لها قيمة مقاومة منخفضة (870 أوم.سم. من ناحية أخرى، أظهرت العينات التي كانت مغمورة في تربة **Buzrgan** أن أعلى ضرر كان عن طريق التآكل التقريبي بسبب ارتفاع نسبة الأملاح القابلة للذوبان وخاصة الكلوريد (7388) جزء في المليون والكبريتات (2570) جزء في المليون.

### 1. Introduction:

External corrosion is one of the most complex problems of buried or submerged installations. In general, external corrosion is a widespread problem in underground pipelines[1]; pipelines transporting crude oil for long distances and buried in different environments are subjected to this kind of damage, which causes significant economic problems, environmental and safety hazards. Studying the phenomenon of external corrosion in a specific environment and specific metal gives an opportunity to overcome the causes of the problem or at least to know the circumstances that will cause the problem and thus determine when the operator must be careful in dealing with the facility in similar circumstances. The external corrosion of steel pipelines is a function of soil properties, including pH, ion concentration, oxygen, temperature, and moisture content. The severity of corrosion differences that develop on underground pipelines is as a result of these factors [2] Differences in soil properties, the basic constituents of the soil, variation in the moisture content of the soil, the depth from the surface or oxygen barriers, differences in the pH, or the concentration of soluble ionic species such as chlorides in the soil, can produce differential corrosion cells [3] Underground corrosion of pipelines is predominating the result of differential corrosion cells. Due to the relationship between

corrosion and conductivity, resistivity has been considered the main variable to study in the field of soil corrosivity [4]. Table (1) illustrates corrosivity ratings based on soil resistivity according to American Society for Testing and Materials (ASTM G187).

**Table (1) Tendency to Corrode Based on Soil Resistivity [4]**

Soil Resistivity Class (ohm-cm)	Tendency to Corrode
>10,000	Very mildly corrosive
5001–10,000	Mildly corrosive
2001–5000	Moderately corrosive
1001–2000	Severely corrosive
501–1000	Extremely corrosive
0–500	Extremely corrosive

The big challenge that can be exposed for the buried pipeline is transporting the ingredients from the oil exploration site to several miles away from cities and towns and production units like refineries, since they are inflammable, and thus, any degradation due to corrosion such as leakage can cause a severe accident, leading to an explosion. The damage that may occur to the transport system due to corrosion has several risks, including economic, environmental, or maybe procure to accidents or lead to loss life of people [5]. So it was necessary to keep the pipes from the corrosion conditions surrounding it and to maintain the longest life of the pipes as well as taking into account safety and environmental preservation [6]. The objective of the present work is improving the understanding of corrosion behavior through studying the susceptibility to corrosion of low carbon steel pipeline API 5L X52 in soil environment under protection failure. In addition to provide a best understanding of the relationships between soil parameters and the corrosion defects.

## **2. Experiments:**

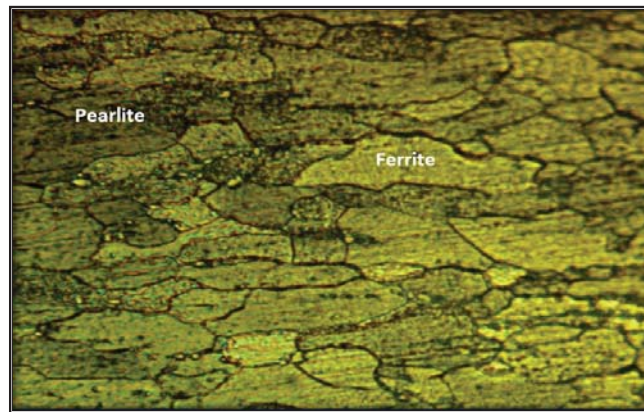
### **2.1 Material:**

The material sample used in the present study was a piece of pipeline API 5L X52 (is the same as the 28" export pipeline metal used in the MOC field), Table (2) shows the chemical composition analysis of this sample, was carried out by metal analysis SPECTRO at General Company for Inspection and Engineering Rehabilitation- Baghdad. The microstructure of the sample was observed by using an optical microscope, as shown in Figure (1). The microstructure of the sample was observed by using an optical microscope type TOUPTEK

PHOTONIC AMA050. This test was done at the University of Babylon - College of Materials Engineering - Department of Metallurgical.

**Table (2) Chemical Composition of Pipeline under Study**

Chemical element %	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
Sample of pipeline	0.125	0.254	1.46	0.0143	0.0073	0.0181	0.002	0.0108	0.0429	0.015	Bal.



**Fig. (1) Microstructure of Low Carbon Steel API 5L X52, at 400X Magnification**

## 2.2 Corrosion tests

Simple immersion test (weight loss) measures the advance of corrosion damage which gained when immersed the samples into corrosive environment, studying the corrosion rate to know the behavior of material in corrosive environment. Steel samples were machined to the required dimensions (25, 25, and 6) mm length, width and thickness respectively. Each of the steel samples were subjected to the annealing practices at (650°C) for one hour in order to remove residual stresses and then cleaning it by emery paper to grade 1200, then washed and dried. Weighed samples of the low carbon steel were placed in to plastic containers of soil that collected from the field at a depth of 1.2 meters nearby a buried pipeline (field conditions). This test was carried out by immersing the steel samples in the soil at different moisture rates (due to soil moisture varies during seasons) with three levels of moisture that done depending of local moisture taken in the summer season, June. Demineralized water was added to reach

for (5, 10) % in addition to the local moisture for soil. The time of immersion was (7, 15, and 30) days respectively, after a reasonable interval, the samples were cleaned from corrosion product and weighed to measure the lost weight for each sample. A calculation of average corrosion rate, expressed as a uniform rate of thickness loss per unit time in millimeters per year (mm/y) [7]

$$CR = \frac{W \times 365 \times 1000}{ATD}$$

Where:

CR = average corrosion rate, millimeters per year (mm/y)

W = mass loss, grams (g)

A = initial exposed surface area of specimen, square millimeters (mm<sup>2</sup>)

T = exposure time, days (d)

D = density of coupon metal, grams per cubic centimeter (g/cm<sup>3</sup>)

On the other hand, electrochemical experiments (polarization experiment was done using potentiostat instrument) were performed in a conventional three-electrode cell accommodates for 400 mL solution (The electrolytes studied were an aqueous extract of the soil). An Ag/AgCl and a platinum foil were used as the reference and counter electrode, respectively; the process has been programmed in computer to draw potential (mV) and log current (μA) to obtain corrosion current by intersection of the tangents to the two polarization curves. Potential quoted in this paper was referred to the Ag/AgCl. Whereas, the polished API 5L X-52 steel sample with its total surface area of 1 cm<sup>2</sup> was used as the working electrode. Open-Circuit Potential (voltage versus time) was recorded every five minutes for specimen in the corrosion solution which is aqueous extract of the soil. The voltage was measured of open circuit potential (O.C.P) as a function of time till steady-state potentials. This test was done at the University of Babylon - College of Materials Engineering - Department of Metallurgical. The general equations applied for the determination of corrosion rate by current density in solution on the steel during electrochemical reactions are [8]:

$$\text{Corrosion rate (mpy)} = 0.13 \times I_{\text{corr}} \cdot E_w / \rho$$

Where:

$I_{\text{corr}}$ : Corrosion current density μA/cm<sup>2</sup>.

$E_w$ : Equivalent weight (for low carbon steel X52 = 27.78) Calculated according to ASTM G102

$\rho$ : Density of metal (for low carbon steel = 7.85 g/ cm<sup>3</sup>)

### 2.3 Surface Analysis

Morphology and micro- analysis experiments were carried out by scanning electron microscopy and Energy dispersive X-ray spectroscopy (SEM/EDS) on metal surface that was exposed for corrosion environment in simple immersion test, the time of exposure was 30 days in soil with local moisture (field condition). This morphologic information together with the elemental composition analyses could shed light on possible metal and soil interaction.

### 2.4 Soil survey

Soil is the environment of corrosion in this study, thereby it is important to study its properties and know the chemical composition for it. Sample was collected from Buzurgan region near the exporting pipeline.

#### 2.4.1 Soil Resistivity Survey

Resistivity measurements indicate the relative ability of a medium to carry electrical currents. The soil resistance can be measured directly by using the four pins- winner method, the soil resistivity measuring device was (EP-TECH) model: (EPT/124F) made in Canada. It has been borrowed from Al-Taakhe Engineering Company. as shown in Figure (2).



**Fig. (2) Soil resistivity meter device**

The resistivity ( $\rho$ ) is then [9]

$$\rho = \pi a R$$

Where:

$\rho$  is soil resistivity ( $\Omega \cdot \text{cm}$ )

$a$  is electrode separation (cm)

$R$  is resistance ( $\Omega$ )

#### 2.4.2 Moisture Test for Soil

The moisture content of the sample of the site nearby transport pipeline in Buzurgan reign was tested in the laboratory, the soil sample was weighed then dried at temperature of (110 °C), a sample allowed to dry for 15 to 16 hours after that dry weight was taken. This test was carried out in Missan Oil Company – Department of Engineering Inspection – Corrosion Laboratory.



**Fig. (3) BINDER Drier Oven**

The soil moisture calculated as following[10]:

$$A\% = [(B - C)/(C - D)] \times (100)$$

A = Moisture percent

B = Mass of original (wet) sample, and container

C = Mass of dry sample, and container

D = Mass of container

### 2.4.3 pH Test for Soil

This test was used to determine the pH of a soil. The principle use of the test is to evaluating the corrosivity of a soil environment and information on the stability of a metal as a function of pH [11].

### 2.4.4 Chemical composition analysis for soil sample

Chemical composition analysis (XRF, XRD and Soluble Salts Examination) was carried out for the soil samples after collecting them from the site to know the percentage of the elements and components. This analysis was done using soil analysis SPECTRO of model SPECTRO XEPOS and X-ray diffraction by D2 PHASER these tests done at Baghdad university- department of geology-Iraqi Germany laboratory. Examination of soluble salts was carried out to determine the ratio of chloride and sulfate in soil samples, this examination was conducted in Missan Oil Company, in the laboratories of the Research and Quality Control Department.

## 3. Results and Discussions

Experimental results of the soil sample are given in Table (3).

**Table (3) characteristic of Buzrgan soil**

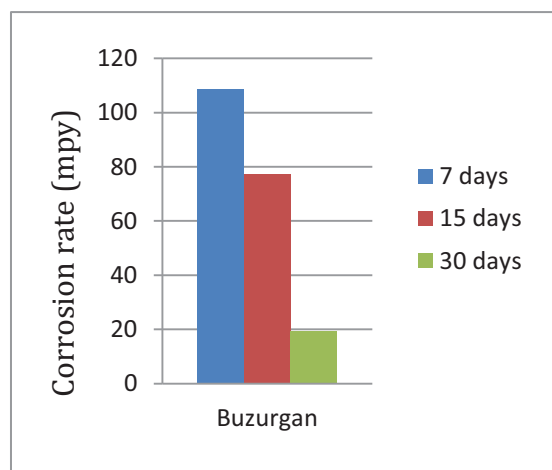
Moisture content%	pH	$\rho(\Omega.cm)$	CaSO <sub>4</sub> .2H <sub>2</sub> O %	SiO <sub>2</sub> %	CaO3 %	Na%	Mg%	K%	Ca%	Cl- (ppm)	SO <sub>4</sub> <sup>-2</sup> (ppm)
12	8.36	870	18.8	25.4	33.1	8.452	3.192	1.1	25.9	7388	2570

As a result, the reading of soil resistivity (at a depth of approximately 1.2 meters of buried pipes), gives an indication that corrosivity of soil is extremely corrosive according to ASTM G187-12a. Corrosion is proportional to electrolyte (moist soil) pH. In general, steel's corrosion rate increases as pH decreases when soil resistivity remains constant[10]. In 2012, Research showed that pH is not a prevailing factor in the corrosion mechanism when the soils have a pH in the range of (4-8.5) [12]. Table (3) illustrates the result of pH measurement for soil, this results show that the soil is alkaline. However, of the above it can be considered that pH is not a dominant factor of making the soil more corrosive environment. It is seen from the tables above that the presence of large amounts of aggressive ions such as chlorides accelerates



corrosion in the metal surface, if the concentration of chloride in soil greater than 5000(ppm) the degree of corrosivity is classified as sever [13]. In addition to increasing the likelihood of pitting corrosion, a research study conducted in Al-Faw reign (southern Iraq) showed that the surface of the metal was clearly degraded likewise pitting corrosion is so clear on the steel pipe specimen surface due to the high chloride content in the soil [14]

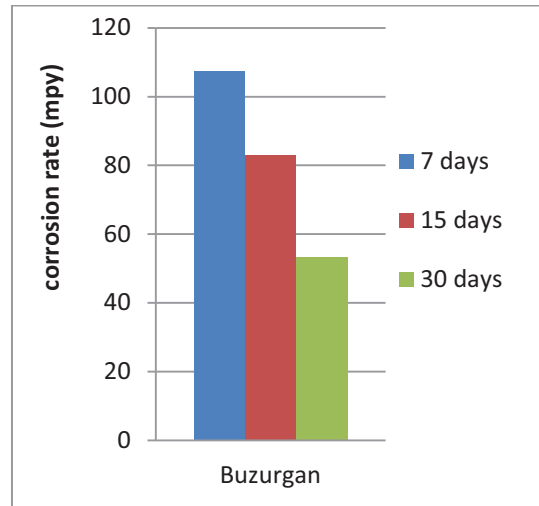
On the other hand, the presence of chloride tends to decrease of the resistivity [15]. This corresponds to the low resistivity values of the studied area. In contrast, high concentrations of calcium and magnesium in soils tend to make it alkaline, this seems clear of pH measurement. As for the sulfate ions, they have lower risk than chloride relative to corrosive effect. However the risk may increase in case of the sulfate-reducing bacteria (SRB) is presence. The steel corrosion processes started when the steel sample were exposed to natural soil. When the soil moisture content was local, corrosion rate of steel samples decreased as immersion time increased. This behavior is shown in Figure (4). When the soil moisture rises up to 5% of the local moisture, the behavior of samples remains constant, but the rate of corrosion increases when moisture rises, this illustrates in Figure (5). Although the soil moisture has risen to double of the ratio used in second experimental (10%), the metal's behavior has not changed; this is evident in Figure (6)



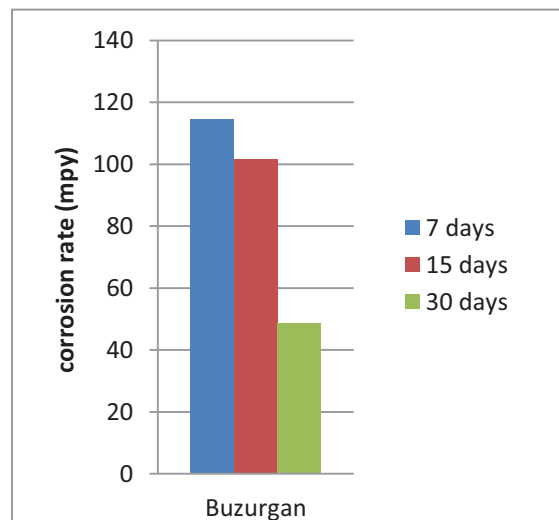
**Fig. (4) Corrosion Rate (mpy) at Local Moisture**

The results show when the time of immersion increases the corrosion rate decreases. due to the formation of corrosion product layer whereas the time increases as the thickness of this layer increases; this agreemeent with another researechers [16][17] This is due to corrosion products, on the steel surface becomes thicker and more compact with immersion time. Researchers

showed a direct correlation between the moisture content and the corrosivity of soil and which is considered a relevant parameter in assessing the corrosivity of soils[9] Therefore, a factor such as soil moisture must be taken into account when studying corrosion in buried pipeline.



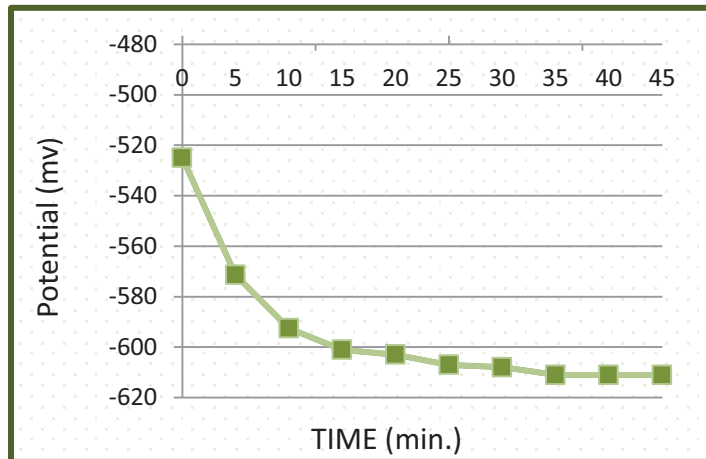
**Fig. (5) Corrosion Rate (mpy) at (5%) Moisture Content**



**Fig. (6) Corrosion Rate (mpy) at (10%) Moisture Content**

On the other hand, before polarization, the open circuit potential of the working electrode was measured as a function of time until the saturation and the quasi-stability obtained. From Figure (7) it can be noted that during (0-5) minutes the corrosion potential decreases at greatest speed, this is due to the formation of metal oxide on the surface, then the corrosion potential decreases slowly due to the growth of oxide film which improving corrosion protection ability.

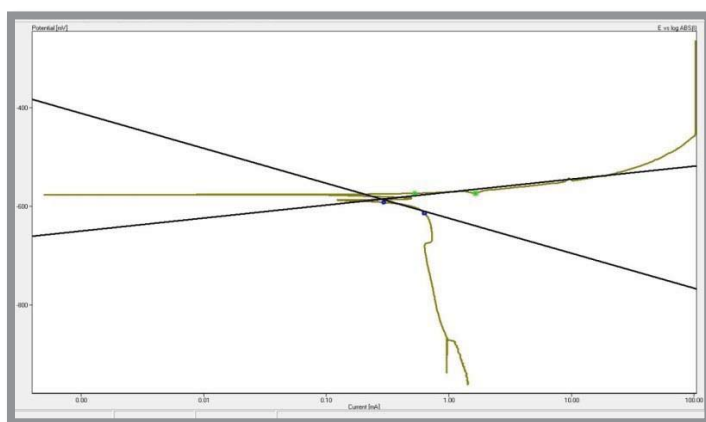
Also, it can be noted that the corrosion potential reaches a level at which the corrosion potential stabilizes. The constant OCP means that there is equilibrium between dissolution and deposition [15].



**Fig. (7) Open Circuit Potential Curves for X52 in Aqueous Extract of Buzargan Soil**

The polarization tests were achieved in aqueous extract of the soil. The open-circuit potential measurements provide good information about the starting of polarization curves, where run the polarization device with potential range ( $\pm 350$ ) starting from open circuit potential.

The potential – Log current density plots, obtained from polarization of X52 samples with aqueous extract of soil are shown in Figure (8). The values of polarization parameters of X52 sample with aqueous extract of Buzargan are shown in Table (4). The corrosion current density reaches to ( $285.36\mu\text{A}/\text{cm}^2$ ).



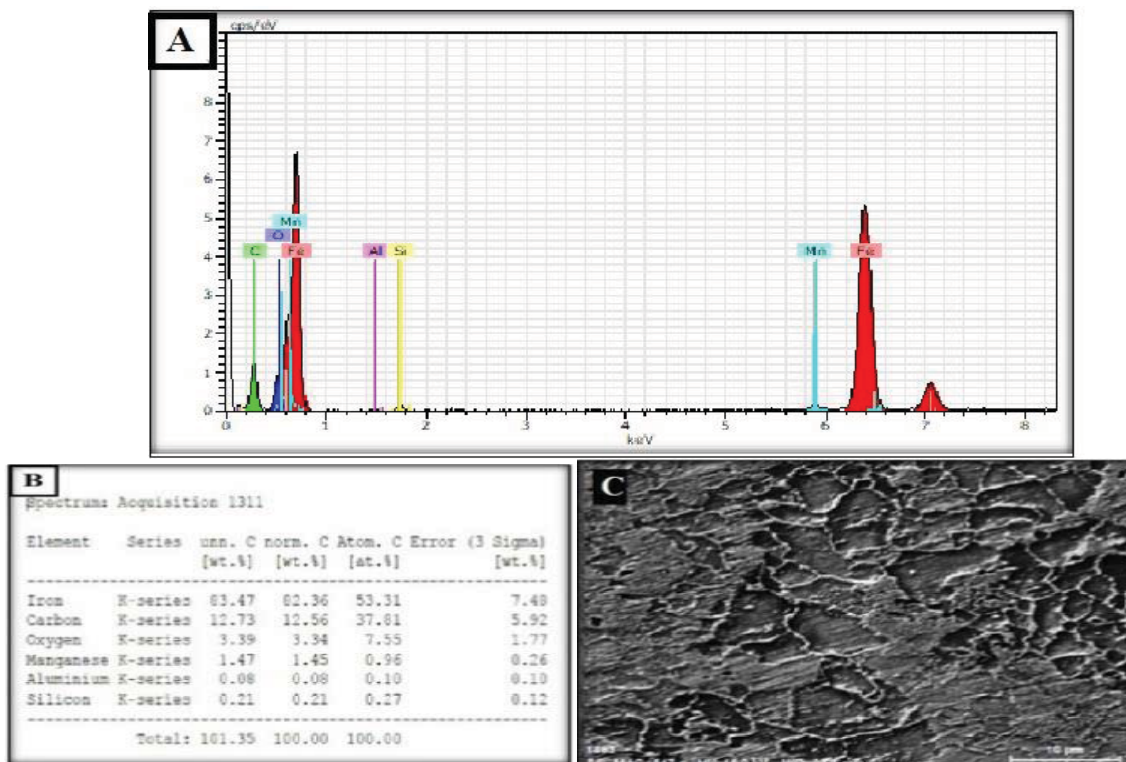
**Fig. (8) Polarization Curve for X52 in Aqueous Extract of Buzargan Soil**

The value of corrosion rate shown in Table (4) indicates that the highest rate of corrosion. This corresponds with the result of simple immersion test as previously indicated. It was found that the high percentage of soluble salts in the soil, especially chloride and sulfate is the cause of high corrosion rates. As a result, the rich soil by soluble salts; it has highest conductivity that leads to increase the corrosion rate[18].

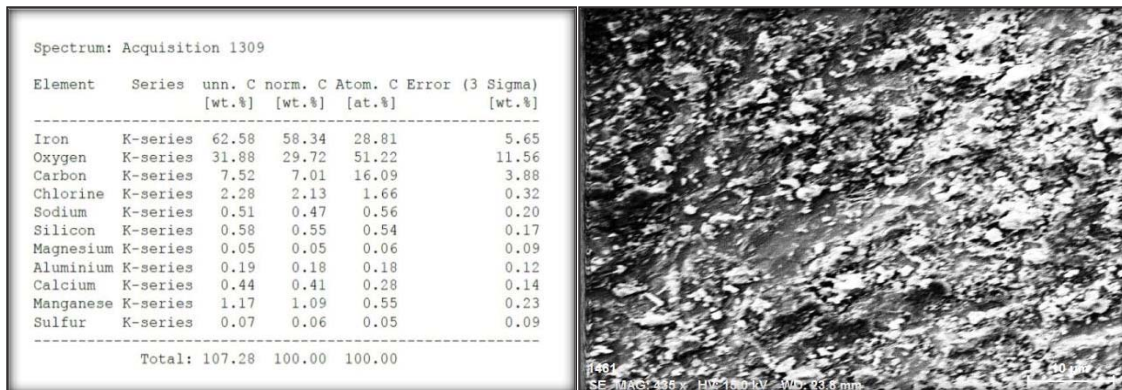
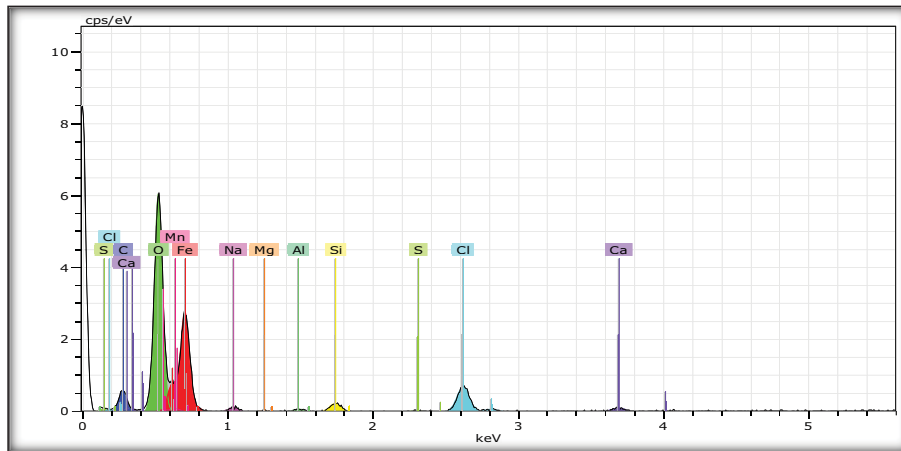
**Table (4) corrosion parameters for polarization of API X52**

Site	Current density ( $\mu\text{A} / \text{cm}^2$ ) $I_{\text{corr}}$	Corrosion rate (mpy)	$E_{\text{OPC}}$ (mV)
Buzurgan site	285.36	131.28	-610

Figure (8) illustrates the chemical composition obtained from the surfaces of samples before immersion (base matel), Figure (9) shows (EDS) analysis employed to determine the chemical composition of the corroded surface for the sample buried in soil along 30 days.

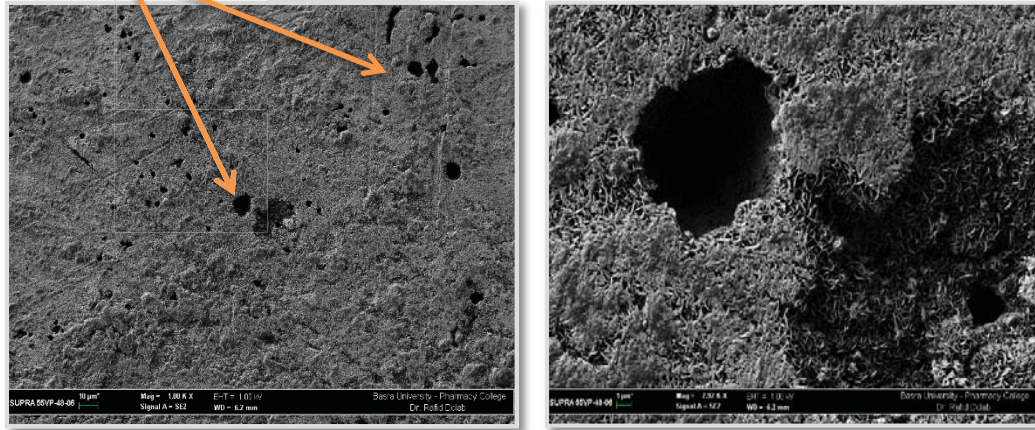


**Fig. (9) A. EDS Analysis, B. Composition Table, C. SEM Image with High Magnification before Corrosion**



**Fig. (10) A. EDX Analysis, B. Composition Table, and C. SEM Image with High Magnification after Corrosion (Buzrgan soil)**

The EDS for the low carbon steel surfaces after immersion test demonstrates that iron and oxygen have been distinguished, which prove the formation of a corrosion product layer. Sample SEM micrograph images of the surface of corrosion samples are shown in Figure (10), with magnifications ranging from 1000× up to 10000. Results from the tests show that damage to the API 5L standard carbon steel X52 (30 days exposure) is significant in this soil environment in terms of surface penetration either as a uniform corrosion or experienced localized corrosion in the form of pitting. With regards to the carbon steel samples, the appearance of (pitting) surfaces when viewed at high magnification were very different from the original metal before exposure to the corrosive environment (wet soil). It can be concluded that the mild steel surface corroded in aggressive media has areas with clearly high chloride concentration.

**Pitting**

**Fig. (11) Scanning Electron Microscopy Micrographs of X52 (Buzargan) with Magnifications Ranging from 1000× up to 10000x**

### Technical and economic feasibility

Buried pipeline transports the ingredients from oil exploration site to several miles away from cities and towns, the cost of their construction amounts up to millions of dollars, in addition to the difficulties associated with this type of work, like passing through agricultural lands, rivers, seas, mountains, marshy areas, and desert and may be cross other services like paved roads, railways, transmission lines, underground pipes/cables, and so forth. Motivations of the present work is to achieve the aspiring aim of cost-effectively by maintain the existing pipelines, and extending its safe operating life.

### Conclusions

- 1- According to ASTM G187-12a, Buzargan soil is considered as extremely corrosive.
- 2- The pH readings of the soil indicate that it is alkaline soil, and is a non-influencing factor in the process of corrosion.
- 3- Moisture content for soil has great effect on corrosion process. Because it provides an excellent electrical conductivity, where increasing humidity increases electrical conductivity
- 4- The presence of large amount of aggressive ions like chloride and sulfate accelerated the corrosion and it is the primary cause for the appearance of pitting corrosion.
- 5- The exporting pipeline that passes through Buzargan region works in harsh environmental conditions.

6- The external surface of underground pipeline should be protected by full cathodic protection system working accompanied with coating to get the structural integrity of buried transmission crude oil pipelines.

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