Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Factors Influencing Corrosion of Underground Metal Pipes in Clay Soil

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ARTICLE INFO

ABSTRACT

Pipeline corrosion is a world-recognized problem and has been a major concern for pipeline owners in recent decades. Soil corrosion is significantly different from sea corrosion due to the heterogeneous environment. Therefore, the corrosion study is required at a critical location. This study aims to characterize the influences of soil properties that cause the corrosion of underground pipes which are moisture content, organic content, pH value, and chemical composition content. Soil samples from three areas were taken to the laboratory for test and analysis. The soil samples are tested by four tests moisture content test, soil pH test, organic content test, and chemical composition content test. This study revealed that the soil properties mentioned above are responsible for the corrosion of the underground pipes. The results obtained showed that the soil samples from the three areas which are red clay soil are very corrosive to the underground pipeline.

Keywords:
Underground pipes; corrosion; soil properties; clay soil

1. Introduction

Corrosion is one of the most challenging problems where metals are directly exposed to various soil environments such as soil chemistry and air constituent throughout their designed life. Soil plays an important role in the corrosion process, which is subjected to chemical and mechanical processes. Soil corrosion is defined as the deterioration of metal or other materials brought about by chemical, mechanical, and biological action by the soil environment [1].

Soil corrosiveness is a major threat to the integrity of underground pipelines, which has contributed to about 65% of the corrosion of buried iron [2]. The failure of these pipelines was usually

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https://doi.org/10.37934/araset.65.1.2736

accompanied by a high degree of environmental, human, and economic consequences [4,5]. Research has established factors that influence the corrosion of buried pipelines in soil. These factors include moisture content, pH level, organic content, and chemical content [1-8]. Due to the prevalence of mineral salts and water content, soil is generally assumed to be a good electrolyte for corrosion [9]. In general terms, soils with poor aeration, high electrical conductivity, moisture content [10], and high soluble salts are considered corrosive soils [11]. Clay soil is expected to be more corrosive than other soil types [12].

This paper presents the findings on soil properties that contribute to the corrosion of underground pipes. A critical location affected by soil corrosion was identified and three soil samples were collected around the site location. Figure 1 shows the actual corroded underground pipe at the identified location. This underground pipeline was made by galvanized iron (GI) pipes insulated with bitumen tape. These pipes were buried between one meter to two meters to carry water for a fire sprinkler system.

Fig. 1: The external corrosion of underground GI pipe

Corrosion can be affected by several factors which are pH value, soil resistivity, electrical conductivity, dissolved oxygen, water temperature, type of pipe, potential difference, surface condition, aeration flow velocity, concentration, and bacteria [15-16]. The pH value is one factor that enhances the metals' corrosion [16]. Acidic soil will enhance the chemical process of the corrosion that coincides when it reaches certain conditions for example the corrosion of metals happens when the moisture content of the soil is higher [17]. Soil has a much higher risk of corrosion in structural materials such as steel when it has higher acidity. This happens due to the higher concentration of hydrogen ions, H^+ in the soil where it reacts with the iron and oxygen to produce hydroxide as a cathodic reaction product. In contrast, hydrated iron oxide is an anodic reaction product for ensuring electrobalance [16]. As shown in Table 1, the pH scale ranges from 0 to 14; which is a pH of 7.0 and represents the point where acid and alkaline materials are in balance. Water with a pH value below 7.0 is considered acidic, while water above 7.0 is alkaline. Total alkalinity refers to the total bases in water that can neutralize acid. These include bicarbonates, carbonates, hydroxides, and some phosphates and silicates. Groundwater can be acidic or alkaline in pH, depending on several factors. As water percolates through the soil, it can come in contact with acidic materials such as decaying organic matter.

Table 1
Effect pH Range on Corrosion Rate

Type of soil	pH value range	Corrosion rate
Extremely acid	< 4.5	▲
Very strongly acid	4.5 – 5.0	
Strongly acid	5.1 – 5.5	
Medium acid	5.6 – 6.0	
Slightly acid	6.1 – 6.5	Least
Neutral	6.6 – 7.3	
Mild alkaline	7.4 – 7.8	
Moderately alkaline	7.8 – 8.4	
Strongly alkaline	8.5 – 9.0	
Very strongly alkaline	9.1 >	▼

The moisture content of soils plays a major role in the corrosion of buried ferrous metal pipes until a limit is reached where a decline in corrosion rates takes place. Soil that has high moisture content has a big impact on the corrosion of buried metals. Moisture content acts as a basic component that goes about as an electrolyte for the corrosion process and can influence corrosion development straightforwardly. Three types of sources provide soil moisture which are free groundwater, gravitational water, and capillary water by and large, the corrosion rate increases with the expansion of moisture content [16,17]. At low water content, iron will be rapidly oxidized by oxygen into a protective film which would prohibit the diffusion process, resulting in polarization in the corrosion electrode. A relatively higher level of water content can prompt the diffusion of ferrous ions [18]. In addition, a high level of water content will facilitate the transport of ferrous irons through the graphitized layer on the iron pipe's surface after the initiation of corrosion [18].

Several researchers have investigated the effect of moisture content on the corrosion of buried ferrous metals. Gupta and Gupta [20] performed laboratory tests on steel specimens exposed in soils taken from three locations in India. It is noticed that mass loss increases with increase in moisture contents up to intermediate moisture content. They found 65% water holding the capacity to be the limit for the soils. Noor and Al-Moubaraki [21] also examined the effect of moisture content on the corrosion behavior of ×60 steel in soils of different cities at an ambient temperature of 29±1 °C. Their study further confirms that moisture content and the corresponding corrosion of buried pipes depend on the soil's properties and its type.

Chemical composition content can enhance the corrosion reaction of the underground metal pipes. Chloride particles and sulfate particles are commonly harmful and increase the reaction of anodic disintegration of metals [23]. This happens when the concentration of chloride particles is inclined to significant varieties depending on the level of soil moisture content [24]. Chemical components that are most identified with corrosion are chlorides, sulfates, and other ions. Chloride particles are commonly harmful because they take an interest legitimately in the reaction of anodic disintegration of metals and will decrease soil resistivity.

Corrosion may be produced by the presence and activity of microorganisms. Organic matter in soil is relevant to the electric potential gradient. Available nitrogen, potassium, and phosphorus are relevant to anions [23]. The properties of organic matter and the carbonate content that the soils present have relevant implications in the corrosion process. This could appear as the result of clay soils rich in humus, which are very cohesive and inhibit the formation of an anticorrosive surface layer on the metallic object, something that other soil environments allow [23-26].

2 Methodology

This study was conducted to characterize the properties of soil surrounding the underground pipeline which responsible for the corrosion. Four tests were conducted; soil pH value, organic content, moisture content, and chemical composition content to determine the responsible properties that cause the corrosion of underground pipes. The soil sample was taken from three different areas and a depth of about one meter from ground level from the actual site. The area that was selected to collect the soil sample was cleaned and all the debris on the surface has been removed. The top surface soil was removed from the vertical face of the pit where sampling is to be done by using a shovel to expose fresh soil for sampling. After that, the collected soil sample was filled in the labeled plastic bag by using the scoop. These collected soil samples were taken to the laboratory for test and analysis. Preparation of samples was preserved by ASTM D 4220-95 Reapproved, 2000-Standard Practices for Preserving and Transporting Soil Samples and ASTM G162-99 (American Society for Testing and Material, 2010).

2.1 Soil pH Value

The soil pH was measured by BS 1377: Part 3: 2018 standard by using an electronic pH meter. The testing involved the volume fraction of the suspension of soil in water as 1:2.5 for testing the pH of the 5g of soil sample by adding 12.5mL of distilled water. The pH value of the sample was measured by using the electronic pH meter after 10 minutes.

2.2 Moisture content

This testing was conducted to derive the initial moisture content of the soil sample based on BS1377: Part 2: 2018. The cleaned and dried container with lid was measured and recorded as W. 10g of soil sample was prepared and the mass was recorded as W2. The soil sample was kept in the oven with the lid removed for drying in maintaining the temperature between 1050°C to 1100°C for 16 to 24 hours. After the cooling process, the dried soil sample was weighted and the data was recorded as the final constant weight as W3. The average moisture content of the soil sample was derived by using Eq. (1);

$$\text{Moisture content} = \frac{W2 - W3}{W3 - W1} \times 100\% \tag{1}$$

Where W1 is the weight of the empty container, W2 weight of the sample with the container, and W3 dried sample with the container.

2.3 Organic Content Test

The most common method used to estimate the amount of organic matter present in soil samples is by measuring the weight loss by an oven-dried 105^{o}C soil sample when it is heated to 440^{o}C accordance with ASTM D2974-20e1; Standard Test Methods for determining the water moisture content, Ash Content and Organic Material and Other Organic Soils. The organic content of the soil is given by Eq. (2);

$$\text{Organic content, OC} = \frac{Mo}{Md} \times 100\% \tag{2}$$

2.4 Chemical Composition Content

In this study, X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques were used together to characterize the clay soil sample. X-ray Diffraction (XRD) was performed to determine the phases present in a material. The chemical composition content in the soil was tested using XRD at room temperature. About 5g of powder soil sample was placed on the sample holder and the samples were directly scanned at CuKα radiation (λ = 1.5406 Å) and 2Θ configuration between 20° to 80° at the step size of 0.02°. XRD pattern will be analyzed using DIFFRAC.EVA software. The pattern gained was used to clarify the chemical composition content in a soil sample. The major element composition of the soil powder sample was determined by using an Energy-Dispersive X-ray Fluorescence Spectrometer (EDXRF). Bruker M4 Tornedo XRF was used for this test. Same as XRD, about 5g of soil powder samples were placed in a sample holder and directly scanned and analyzed.

3 Results

The findings on relevant results and discussion about the involvement of the soil properties in the corrosion process of the underground pipeline are being further analyzed in the previous study on this field.

3.1 Soil pH

Soil is considered an alkaline medium when its pH value ranges from 8 to 14 while it is acidic when the pH value ranges from 1 to 6 [27,34]. The pH of the soil is tested based on BS ISO 10390:2005. Table 2 shows the result of the pH test of soil samples. The collected data from the pH test showed that the soil sample fell within the very strong acid with an average pH value of 4.3 – 5.0. Hence, this soil sample's pH measurement proved that this soil is more acidic and highly corrosive to the underground pipeline which is the condition consists of increasing concentration of hydrogen ions. The higher concentrations of hydrogen ions cause the oxidation process of metal pipes to produce hydrated iron (III) oxide or rust [33].

Table 2
The pH values for the tested soil samples

Area of test	Sample 1	Sample 2	Sample 3
pH reading	4.5 – 5.0	4.5 – 5.0	4.3 – 4.5

3.2 Moisture Content

The moisture content of the soil sample is tested according to the BS1377: Part 2:1990 standard. From the testing done, the percentage of moisture content of this soil is 50% - 65% which is a higher range than the normal range based on the study carried out by Yahaya *et.al*. [29]. The critical moisture content of soils in the corrosion of steel when it is above 50% of its holding capacity [22]. Table 3 shows the soil particles have more space to absorb the water from external forces such as rain and groundwater levels. As a finding of this testing, excess moisture content of the soil will promote the corrosion of underground pipes as mentioned in 2.2.

Table 3
Moisture content in tested soil samples

Number of tests	Sample 1	Sample 2	Sample 3
Moisture content	54.93	57.88	62.73

3.3 Organic Content Test

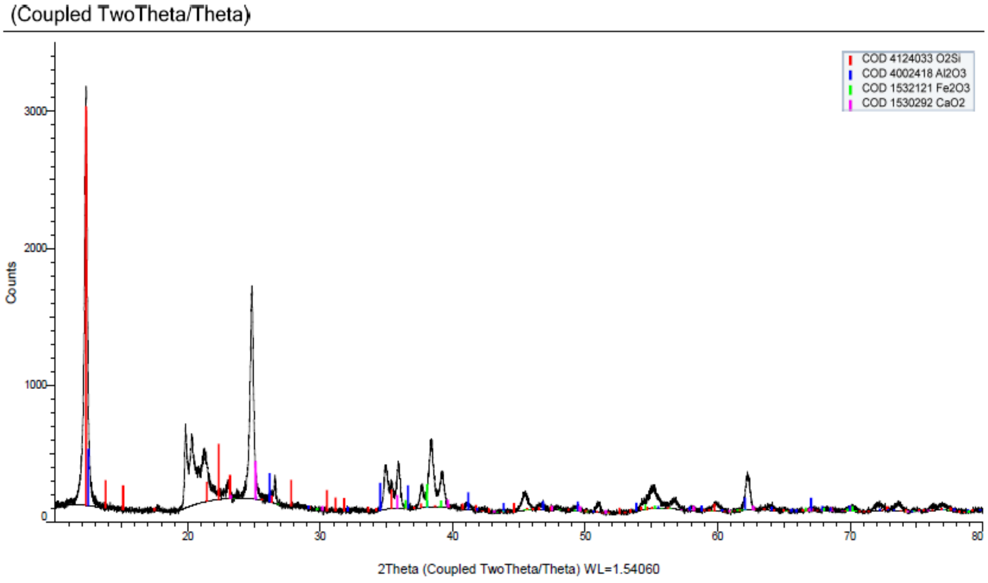
According to J.R. Myers *et al.,*[38], soils containing large quantities of organic matter can be corrosive. Stagnant groundwater in soil may provide favorable conditions for microbial attack. From the results in Table 4, it can be observed that soil Sample 3 is likely to be more corrosive because higher of organic content, while soil Sample 1 and Sample 2 also display a high value of organic content which makes them corrosive to the pipeline.

Table 4
Organic content in tested soil samples

Area	Sample 1	Sample 2	Sample 3
Organic content (%)	35.7	36.3	36.1

3.4 Chemical Composition Content

The results of XRD analysis showed silica oxide, SiO_2, iron oxide, Fe_2O_3, and aluminum oxide, Al_2O_3 are the major constituents in this soil sample. SiO_2 showed the highest peaks, followed by Fe_2O_3 and Al_2O_3. This XRD pattern of the powder soil sample is shown in Figure 2. The results of XRF analysis in Table 5 and Figure 3 show that the highest percentages were silica, Si, and moderate to low percentages of aluminum, Al, and iron, Fe. Several chemical components enhance the environment for corrosion.



🟥	SiO_2
🟦	Al_2O_3
🟩	Fe_2O_3
🟪	CaO_2

Fig. 2: The graph of X-ray Diffraction of soil samples

Table 5
Chemical Substance in Soil Multipoint Full Area

Element	wt. %	Net norm.
Al	33.85	458
Si	44.08	2180
K	4.12	3702
Fe	17.2	156011

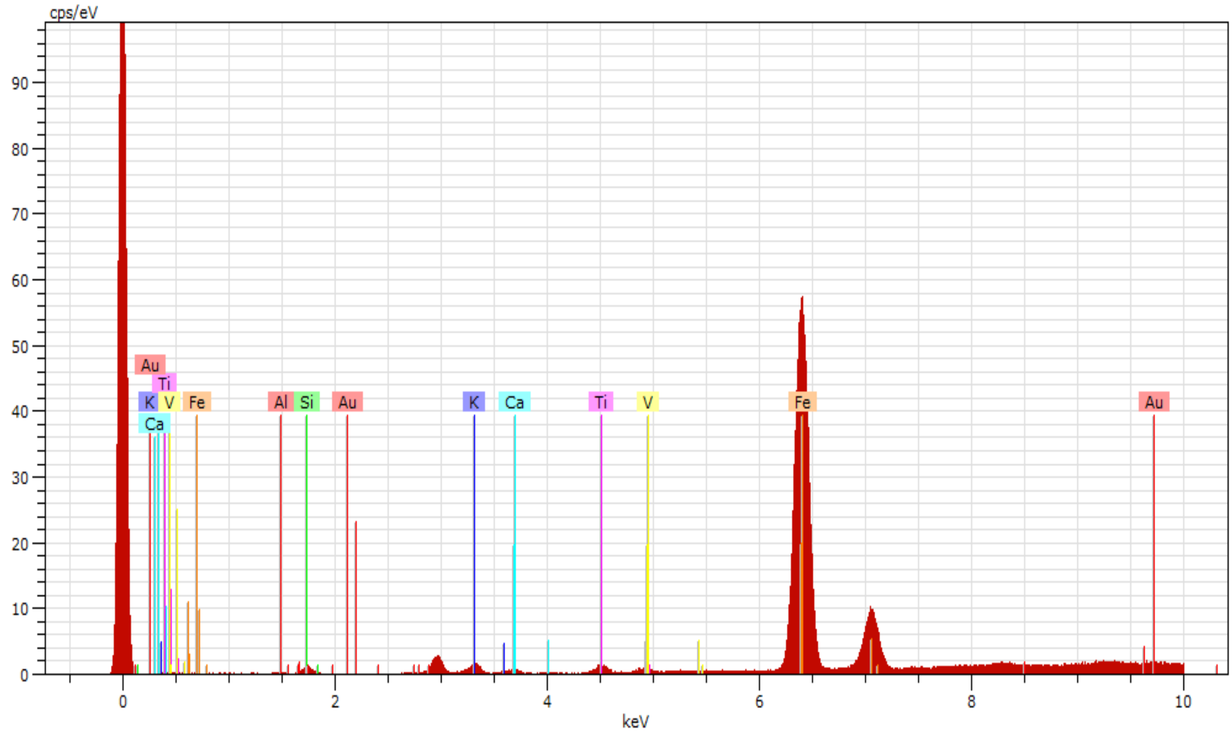


Fig.3: XRF data analysis for soil sample

4. Discussions

The corrosion influencing factors of iron pipes in corrosive clay soil are analyzed. The results obtained showed that all soil samples had lower pH values and high-water content and organic content. Usher et al. stated that while clay soils have pH below 5, it is suitable to grow anaerobes which play a significant role in the corrosion of underground pipelines. The effect of bacteria could cause higher corrosion rates. The magnitude of corrosion can increase with the initial increase in water content [38]. The results showed that moisture content was 50% - 65% which is high. At low water content, iron will be rapidly oxidized by oxygen into protective film which would prohibit the diffusion process. A high level of water content can prompt the diffusion of ferrous ions and will facilitate the transport of ferrous irons through the graphitized layer on cast iron pipe's surface after initiation of corrosion [11,18,20]. Several researchers stated that the critical moisture content is the value where the entire metal surface becomes electrochemical active. Iron will still undergo corrosion by the process of oxidative reaction in water even if oxygen is absent [34].

Corrosion is regarded to occur in an aqueous environment such as this due to the presence of high moisture content. Yahaya *et.al.* stated that water will enter and flow through soil particles governed by soil physical properties including pore and capillary spaces at various zones in the soil profile. Corrosion increases when the moisture content exceeds 50% of the water-holding capacity and decreases as the capacity approaches 100% [32-33]. Ismail and El-Shamy [35] studied that 50% -

60% is the optimum moisture content for maximum corrosion rate. While Norin and Vinka found with increased rainfall, the corrosion rates is higher especially if the precipitation is more conducive to corrosion [36-37]. This makes these soil samples to be corrosive to the pipeline and can cause corrosion damage to the pipe [23].

The composition of the corrosion products analyzed by XRD shows that the clay samples contain peaks corresponding to compositional elements such as F, Al, Si, Ti, and Ca. The dominant peaks are due to the presence of quartz (Si) and iron oxy-hydroxides, such as goethite (a-FeOOH), hematite (a-Fe_2O_3), akaganeite (b-FeOOH), magnetite (Fe_3O_4) and maghemite (c-Fe_2O_3), which are most frequently formed to corrosion happened [39]. From the weight percentage, it is evident that Si content of 44.08% and Al content of 33.85%. The iron oxide content of 17.2% present in the clay will produce a certain definite color depending on the amount of oxide present. The coloring effect arises due to the mixed presence of carbon and iron found in the clay.

5. Conclusion

In this paper, the fundamental knowledge and research related to soil corrosion are presented. The effects of soil properties and their corrosiveness to the underground buried pipeline have been analyzed. This study shows the properties of the soil play an importance role in the corrosion of underground pipes. There are several properties of the soil contribute to the corrosion of the pipes such as the size of soil particles, soil pH, moisture content, organic content, and chemical composition content. The moisture content of the soil is a major factor that influences to the corrosion happens as it acts as the great medium for the iron particles of underground pipes oxidized to produce rust particles. The acidic environment of the soil also enhances the rates of the corrosion of underground pipes due to the excessive hydrogen ions which enhance the oxidation of the metal pipes to ensure the electrobalance of the ions in the soil. Besides that, the size of soil particles is also a factor that can cause corrosion. The finest size of soil particles is classified into clay soil which is considered a corrosive medium due to the mineral content of clay will absorb more water due to its high space between the particles which makes it highly effective in the corrosion of metals. Certain chemical composition content of soil; Fe and SiO_2 also become a factor that influences the corrosion of the underground pipes, when react with water, it will increase the rate of corrosion of the underground pipes.

Most of the structures in the soil are subjected to degradation because of the chemical composition changes in the soil environment due to seasonal changes. Protection measures and wise design decisions are combined to prevent and mitigate underground corrosion. The external corrosion of buried pipes is not preventable despite the use of advanced corrosion protective techniques such as sacrificial anodes, coatings and impressed current [40-42]. The use of protective coating will be proposed to control the corrosion of underground pipelines. There is a wide range of protective coatings that can be used for buried pipelines including fusion bonded epoxy (FBE), multilayer epoxy, or polyurethane coatings. The selection of this coating depends on the soil condition where the corroded pipe happened, which is the soil has high moisture content and high pH values [43].

Acknowledgment

The authors would like to thank the Ministry of Higher Education Malaysia for supporting this research under the Fundamental Research Grant Scheme Vot No. FRGS/1/2020/TK01/UTHM/03/1 and partially sponsored by University Tun Hussein Onn Malaysia. by University Tun Hussein Onn Malaysia.

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