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Effects of Soil Properties to Corrosion of Underground Pipelines: A Review

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Abstract

This review concentrates on corrosion properties that expose to soil environment. Forms of corrosion classified with respect to outward appearance and altered physical properties are uniform attack, galvanic corrosion, erosion corrosion, stress corrosion, crevice corrosion, pitting and inter-granular corrosion. A porous soil may retain moisture for a longer period for optimum aeration and indirectly increase the initial corrosion rate. External corrosion is corrosion attack upon the outside of the pipe soil medium and the most failure mechanisms experienced by buried steel pipelines. Many systems possibly in contact with soil have risk to be corroded such as storage tanks and pipelines.

1. Introduction

Water distribution network plays a vital role in daily uses may deteriorate, cities in Malaysia are facing the prospect of increasing maintenance costs and the decision of whether to replace or repair their water pipeline. The pipeline failures lead in public fatalities, thus, costly affairs in terms of replacement, repair and remedial work. A significant portion of pipeline failures due to aggressive environments which is underground corrosion. The failure of pipeline due to corrosion may contributed to expensive maintenance.

In order to overcome these problems, research and development are established. Corrosion science, a truly interdisciplinary field that includes aspects of physics, materials science, surface science, electrochemistry, and fracture mechanics, benefits by provides a medium for the communication of ideas, developments and research in all aspects of this field and includes both metallic and non-metallic corrosion [1].One challenge for the corrosion science community is to pursue strategies to harvest those diverse benefits and applied to corrosion-related problems. It forms an important link between metallurgists, materials scientists and all investigators of corrosion and degradation phenomena.

Corrosion particularly at the local water utility is not fully understood. Nevertheless, unprotected metal materials are regularly used at the present time, showing that the water industry's lack of attention to the problem. Romer et al. (2004) reported that, 72 % of the materials used for water mains are iron pipe. The stated corrosion is in corrosive soils and tended on the pipe barrel. In addition, pipes are often designed in metallic or cementitious pipe based on hydraulic capabilities rather than to consider the corrosion resistance. It is estimated that the annual direct costs of corrosion for the main distribution system around RM 5 billion [2].

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2. Materials and Methods

2.1 Soil Corrosion

According to National Association of Corrosion Engineer (NACE) International, corrosion is defined as the deterioration of substance or its properties because of a reaction with its environment. Soil corrosion is a process for deterioration of metal in soils that occur in the groundwater in contact with corroding structure. According to Uhlig (2008), water and gas occupy space between solid particles. These spaces can constitute as much as half volume of the dry soil. Some of this water is bound to mineral surfaces, whereas bulk water can flow through porous soil. A porous soil may retain moisture for a longer period of time and allow for optimum aeration. Thus, indirectly increase the initial corrosion rate [3].

Moreover, Uhlig and Roberge (2008) stated that, a piece of iron buried in a dry soil suffers less corrosion than the wet soil. Many systems that in contact with soil have risk to be corroded for examples storage tanks and pipelines. In line with Bureau of Standards test, steel specimens buried in five different types of soil showed that below the surface had greater corrosion [4]. The burst pipe could be a greater problem.. Detailed analysis was undertaken by NACE to establish costs within each sector and applicable to all developed economies, show that Malaysia annual cost of corrosion is about RM6.7 billion from RM207.4 billion of GDP [5].

At a view of that, underground corrosion is a major concern. These especially regarding to pipeline store and transport oil, gas and other hazardous materials. Besides, water distribution system is also one of the elements that should put in accounts. If these substance are released to the environment it can affect the substantial damage and leakage of water. Apart from that, the pipeline corrosion needs to be observed under schedule the inspection programme and frame maintenance. In some cases, replacement of pipelines also must be done [6].

2.1.1 Mechanism in Soil Corrosion

The corrosion process involves in two half-cell reactions as well as electrochemical. The electron released at the anodic sites through oxidation are consumed by the reduction processes at the cathode [8]; [4]. The ability of corrosion process which provided by electrolyte between the anodic and cathodic site. The moisture content of soil act as electrolyte in form of soluble salt such as chlorides, and sulphates contributed to the corrosion process [7]. Besides, an acidic pH also is a good electrolyte because more hydrogen ions are available to act as electron acceptors (AWWA C 105/A25.5-99).

A cell is formed in soil environment is formed by [6]:

i. Pipe under the paving as the anode; most of the attacks are take place close to the edge due to low soil resistivity.
ii. The pipe outside the paving act as cathode; exchange of electrons between the cathode metal and ions, atoms or compounds in the electrolyte.
iii. Soil as the electrolyte; soil media in contact with the anode and the cathode that allows ions to migrate.
iv. The pipe or cable act as connecting circuit; allows the electrons freed from the metal atoms during the oxidation process to move from the anode to the cathode during the corrosion process.

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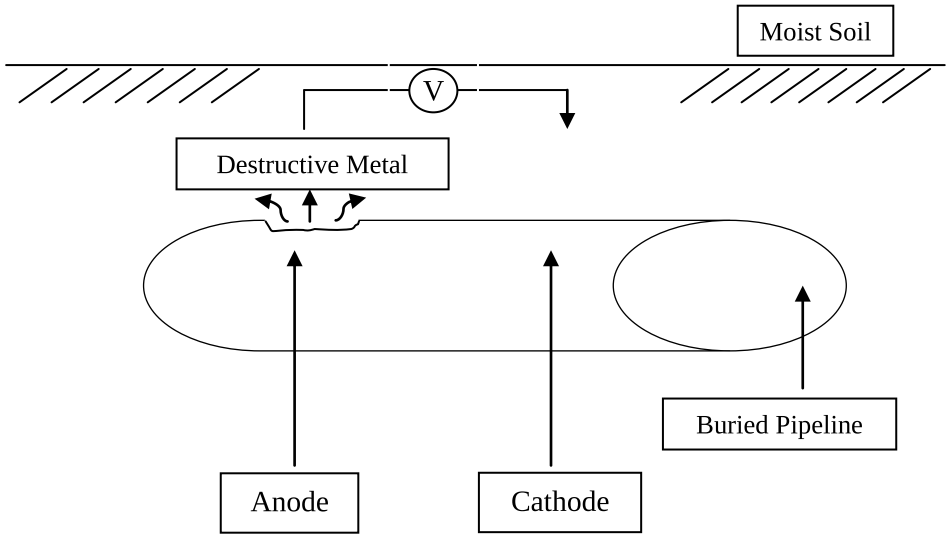

Figure 1.1 Mechanism of Soil Corrosion

Figure 1.1 showing the mechanisms of corrosion in soil environment. Corrosion is influenced by its surrounding environment. The corrosion process will slows down if this path becomes a restriction to electron flow [8]. This study focused on corrosion of underground pipeline subjected to external corrosion pipe. Soils properties want to be emphasized are moisture content, chloride content and pH of soil.

2.2 Elements of Soil Corrosion

External corrosion is corrosion attack upon the outside of the pipe soil medium, and the most failure mechanisms experienced by buried steel pipelines [9]. In general, soil properties comprise pH, moisture, sulphates, resistivity, chlorides and aeration [6]. Soil that containing large concentration of soluble salts in the form sulphates, chlorides, porosity (aeration), electrical conductivity or resistivity, moisture and pH are the most corrosive soils [9]; [6].

2.2.1 Sulphates

Sulphates are more corrosive toward metallic materials than chloride in poorly aerated soils. Sulfate concentration is 2000 ppm or greater represent corrosive condition. These ions are major nutrients to Sulfate Reducing Bacteria (SRBs); facultative anaerobes normally found in soils located near buried pipelines and are a major biological contributor to MIC that produce highest rate of corrosion [10]. SRB utilize sulphate as a terminal electron acceptor during energy generation, producing sulphide as a by-product by the following cathodic reaction in Equation 2.1:

$$SO_4^{2-} + 9H^+ + 8e^- \rightarrow HS^- + 4H_2O \qquad (2.1)$$

The HS^- as product of reduction of sulfate anions typically will interacts with the ferrous iron, produced by the anodic reaction, to give FeS, rather than $Fe(OH)^2$, which is evident by the black encrustations which occur around steel subjected to Microbial Induced Corrosion (MIC) [10].

Groundwaters that test positive for SRB are observed to have greater concentrations 1000-fold of sulfate and phosphate in water trapped beneath the dis-bonded coating on the pipe than in the background soil. SRB attributed to dis-bonded tape coating adhesives in pipeline system, which are function to protect the steel, but can serve as a food source for bacterial metabolism and growth [10].

2.2.2 Chlorides

Chloride can be found naturally in soils as a result of brackish groundwater, historical geological seabeds, or from external sources such as de-icing salts applied to roadways. Generally, chloride involve in

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dissolution reactions of many metallic materials which tends to decrease the soil resistivity. Chloride concentration is 500 ppm or greater represent corrosive environment.

In the anode channel containing acidified chloride ions and ferric ions (2.2), metallic iron corrodes with the cathodic oxidant reduction of hydrogen ions and ferric ions.

$$Fe + [2\,H^{+}aq + 2\,Cl^{-}aq\,] \rightarrow [Fe^{2+}aq + 2\,Cl^{-}aq] + H_2 \qquad (2.2)$$

$$Fe + [\,2\,Fe^{3+}aq + 6\,Cl^{-}aq] \rightarrow [3\,Fe^{2+}aq + 6\,Cl^{-}aq\,] \qquad (2.3)$$

The acidic corrosion reactions remain as long as the anode channel in solution with sufficiently acidic.

2.2.3 Oxygen

Oxygen concentrations are decreased with increasing of soil depth. Oxygen concentration has important effect on corrosion rate either in alkaline or neutral soils as a result of reaction in cathodic reaction. Oxygen supply is higher in coarse-textured, dry soils than in fine and waterlogged textures.

2.2.4 Resistivity

Resistivity is defined as a function of moisture and the concentration of current-carrying soluble ions. It is typically measured in ohm-cm, either in situ or by sampling from the environment. Soil resistivities range from less than 1,000 ohm-cm in soils with high water and ion contents to more than 100,000 ohm-cm in dry sand or gravel [14]. Generally, high soil resistivity will slow down the corrosion activities due to less ionic current flow. Soil resistivity will decrease when the water content and concentration of certain of ionic increase.

2.2.5 Moisture

Generally, electrolyte that supports involves electrochemical corrosions reactions in water saturated or unsaturated soils [6]. Water movement in soils are supported by gravity, capillary action, osmotic pressure from dissolved particles or electrostatic interaction with soil particles. The impact of moisture changes over time can also influence corrosion. For example, a sandy soil in a dry area may not be very corrosive. However, if there is infrequent moisture (from rain) and the soil contains chlorides, there can be highly aggressive which is conditions of high corrosivity. During drying, these chlorides can become concentrated on the surface, making the local conditions even more aggressive.

Several researchers maintain that the critical moisture content is that value where the entire metal surface becomes electrochemical active. Even in the absence of oxygen, iron will still undergo corrosion by the process of oxidative reaction in water [3].Others have shown that corrosion increased appreciably when the moisture content exceeded 50 percent of the water holding capacity and decreases as the capacity (saturation) approaches 100 percent. Stagnant groundwater in soil may provide favourable condition for microbial attack [10].

The critical moisture content of soils in the corrosion of mild steel estimated by Gupta and Gupta (1979) is when it is above 50 % of its holding capacity [11]. The study showed a direct correlation between mass loss in the pipework and moisture content of soils when potential of soil is assumed 65 % of water capacity. This is shows later by Ismail and El-Shamy (2009) studied that 50-60 % is the optimum moisture content for maximum corrosion rate [12]. While, Norin and Vinka (2003) found with increased rainfall, the corrosion rates is higher, especially if the precipitation is more conductive to corrosion [13]; [14].

2.2.6 pH

Soils range from pH 4 to 8 are considered to be less corrosive and not dominant variable affecting corrosion rates [16]. When lower than 4 and higher than 8.5, the soil pH is slight acidic and alkaline. It can be a considerable factor in corrosivity. While at low pH or acidic pH produced from industrial waste, human activities such as agriculture, acid rains, mineral leaching and microbiological activity will lead to serious corrosion risk to buried structure such as steel, cast, iron and zinc [16]; [6]. A neutral pH is the most favorable for SRB that would contribute to MIC.

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Soil pH, by definition, is a measure of the activity of hydrogen ions in the soil solution .The solution increasing in acidic when the hydrogen ions are increasing. Hydrogen ions are hydrogen atoms that have lost its one electron, so it now has a positive charge of one. The H^+ now becomes a great electron acceptor because is seeking to replace the lost electron. The ions (H+) are attracted to take cathode where the freed electrons form the more corrosive the environment becomes [8]. Soils initially become acid when water moving downwards through the profile contains compounds that act as donors of H^+ ions (protons) [15].

For metal corrosion in moisture soil with a near neutral pH, the electrode potential of a corroding metal must be determined by two electrode processes occurring simultaneously, namely oxidation of the metal and reduction of the corroding agent. These half-cell reactions can be represented as eq 2.4 and eq. 2.5 [17]:

Oxidation reaction (anode):

$$Fe \rightarrow Fe^{2+} + 2e^- \text{ (corrosion)} \quad (2.4)$$

Reduction reaction (cathode):

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (2.5)$$

3. Conclusion

This paper explains corrosion mechanisms in soil environment. Pipeline corrosion is extremely complicated and is effected by practically every physical, chemical, and biological parameter in water distribution systems. This work provides key factors that utilise must evaluate in order to mitigate corrosion problems. The consideration potential secondary impacts on corrosion due to compliance efforts for new regulations. Some of the elements that are contribute largely to corrosion in soil environment such as pH, oxygen, chloride, moisture, sulphates and resistivity.

Acknowledgements

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References

[1] National Research Council (U.S.), National Research Council (U.S.), & National Academies Press (U.S.). (2011). Research opportunities in corrosion science and engineering. Washington, D.C: National Academies Press.

[2] Romer, Andrew E, and Graham E. C. Bell (2004), AwwaRF, ExterternalCorrosion and Corrosion Control of Buried Water Mains, Denver, CO.

[3] Eric J. Reardon, Anaerobic Corrosion of Granular Iron: Measurement and Interpretation of Hydrogen Evolution Rates, Environmental Science & Technology 1995 29 (12), 2936-2945

[4] Uhlig, H. H. E. (2008). Corrosion Handbook. Corrosion Handbook Online, 414–418.

[5] A & E Systems, (2008). International corrosion cost facts, 44(Bp 2000), 0–1.

[6] Roberge, P. R. (2008). Corrosion Electrochemistry. In Corrosion Engineering: Principles and Practice (pp. 35–47).

[7] Babor, D. (2008). Pipe Lines ¨C External Corrosion. Bulletin of the Polytechnic Institute of Jassy, Constructions, Architecture Section.

[8] Hopkins, P. (2014). Underground Pipeline Corrosion. Underground Pipeline Corrosion (pp. 62–84).

[9] Doyle, G. (2000). The Role of Soil in the External Corrosion of Cast-Iron Water Mains in Toronto, Canada.

[10] Sherar, B. W. A. (2011), "The Effect of the Environment on the Corrosion Products and Corrosion Rates on Gas Transmission Pipelines".

[11] Gupta SK, Gupta, BK. (1979), "The critical soil moisture content in the underground corrosion of mild steel", Corrosion science. Vol. 19, pp. 171-178.

[12] Ismail AIM, El-Shamy AM. (2009), "Engineering behaviour of soil materials on the corrosion of mild steel", Applied clay science. Vol. 42, pp. 356-362.

[13] Norin M, Vinka TG. (2003), "Corrosion of carbon steel in filling material in an urban environment", Materials Corrosion, Vol. 54, pp. 641-651

[14] V. Chaker, "Corrosion Testing in Soils—Past, Present and Future," in Corrosion Testing and Evaluation, R. Baboian and S. Dean, eds. (West Conshohocken, Pa.: ASTM International, 1990)

[15] Kizhlo M, Kanbergs A. (2010), "The causes of the changes of soil resistivity and the substantiation of prospective experiments", International symposium on power electronics, electrical drives, automation and motion, SPEEDAM.

[16] Pritchard, O., Hallett, S. H., & Farewell, T. S. (2013). Soil corrosivity in the UK – impacts on critical infrastructure Soil Corrosivity in the UK – Impacts on Critical Infrastructure.

[17] Wranglen G. (1985), "An Introduction to Corrosion and Protection of Metals", Chapman and Hall Ltd., Great Britain p. 107.

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