Journal of Tropical Resources and Sustainable Science

journal homepage: jtrss.org

Effect of Bacteria in Soil towards the Corrosion of Water-Pipeline: A Review

N.A.H. Abdul Haris, A.R. Siti Fatimah, M.A. Sulaiman, M.N. Masri*

Faculty of Earth Science, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia.

Available online 3 May 2015

Keywords:
Sulfate, sulfate-reducing bacteria, soil corrosion and pipeline

⌧*Corresponding author:
Faculty of Earth Science,
Universiti Malaysia Kelantan,
17600 Jeli, Kelantan, Malaysia.
Email: najmi.m@umk.edu.my

Abstract

Corrosion is a process of deterioration of metal surfaces where the metals were degraded into another compound. Soil is one of the medium known to have constituted to corrosion of metals. The soil creates an environment for the movement of electrons. The level of corrosion in soil can vary from major material loss or to minor effects. The buried pipelines are exposed to the soil that may experience corrosion attack. The study of the soil as a corrosive environment is important to mitigate the problem which may be serious to the environment and economy. There are few factors that contribute to the corrosion processes. This review focuses only to sulfate and sulfate reducing bacteria in soil. Hence, this review investigates the relationship of sulfate and sulfate-reducing bacteria in soil.

1. Introduction

Corrosion is the process of metal wastage produced by oxidation due to chemical action. The process of corrosion occurs over a period of time and can occur at either high or low temperatures. All material are susceptible to degradation and it is not only restricted to metallic materials (Shaw and Kelly, 2006). The main causes of corrosion are oxidizing agents, acids, bases or galvanic action. There are few types of corrosion which are uniform corrosion, galvanic corrosion, pitting and crevice corrosion, Stress Corrosion Cracking (SCC), corrosion fatigue, erosion corrosion and Microbiologically Induced Corrosion (MIC) (Nimmo and Hinds, 2003).

Electrochemical corrosion which is the most common form of attack to metals occurs when atoms loses electrons and become ions. Corrosion of a steel pipe or a steel automobile panel, creating holes in the steel and rust as the by-product, are examples of this reaction. There are four important components in electrochemical cell which are anode (gives electrons to circuit and corrodes), cathode (receives electrons at the circuit and by-products are produce at cathode), the anode and cathode are connected together electrically and there must be a medium of electrolyte which ensure the anode and cathode are in contact. The four types of electrochemical corrosion are composition cells, stress cells, concentration cells and microbial corrosion.

Various microbes such as bacteria and fungi create conditions that encourage electrochemical corrosion. In aqueous environments, these organisms grow on metallic surfaces (Venzlaff et al., 2013). Microbial corrosion covers the degradation process of metal materials by bacteria and fungi or their by-products that can occur in a range of action:

i. Attack of the metal or protective coating by acid by-products, sulphur, hydrogen sulphide or ammonia.

ISSN Number: 2289-3946

ii. Direct interaction between the microbes and metal which sustains attack.

Biological corrosion has been known to be one of the many reasons of corrosion of pipeline in variety of environments including soil. In this paper, we present a review from papers relating to biological corrosion to estimate the corrosion behaviour related to biological activity. It is estimated that sulphate-reducing bacteria, an anaerobic bacteria influence the corrosion behaviour of buried steel structures by reducing sulphate to sulphide. Its presence influences both the cathodic and anodic reactions occurring on iron surface (Muyzer and Stams, 2008). Biological corrosion is not a type of corrosion but it is the deterioration of a metal by corrosion processes that occur directly or indirectly as a result of living organisms (Fontana, 1987).

2. Materials and Methods

2.1 Corrosion in soil

Corrosivity of soils varies due to its variety of compositions in soil. Tests in one location are generally applicable only to that location (Bhattarai, 2013). Factors affecting corrosiveness of soils are moisture, alkalinity, acidity, permeability of water and air, oxygen, salts, stray currents and the biological organisms (Cao et al., 2012). Most of these factors affect electrical resistance which is a good measure of corrosivity whereas high-resistance dry soils are generally not very corrosive (Chen et al., 2014).

Corrosion is defined as the deterioration of metal structure as a result of the reaction of pipeline in contact with its surrounding environment. Thus, affecting every part of the pipe surface. Corrosion of underground structures is known to be the major source of structural damage of pipeline. Corrosion of pipelines can occur in two conditions, internally and externally (Kakooei et al., 2012). Water plays important role in corrosion which function and act as a medium for the electron transfer between anode and cathode (Baumgartner et al., 2007) .

Living organisms are sustained by chemical reactions where ingest food and eliminate waste product. These processes can affect corrosion behaviour in the following ways;

i. Directly influencing anodic and cathodic reactions
ii. Influencing protective surface films
iii. Creating corrosive conditions
iv. Producing deposits

Many buried-structural materials, such as galvanized water supply pipelines, natural gas and crude oil pipelines have been corroded by soils all around the world (Bhattarai, 2013). Pipeline steels experienced MIC by sulphate-reducing bacteria in the soil environment during the operation in the field (Wu et al., 2014). The bacteria inhabit the metal surfaces causing the production of a thin layer in which is called biofilm and help accelerate the corrosion process (Conlette, 2014).

2.2 Microbes in soil

Bacteria are the major contributors in the carbon, sulphur, nitrogen and phosphorus cycles (Behera et al., 2014). There are two types of bacteria namely aerobic (sulphate-oxidising bacteria) and anaerobic bacteria (sulphate-reducing bacteria). The carbon steel degradation can be attributed by the alteration of the environmental condition by hydrogen sulphide producing microorganism. The most recognised group of hydrogen sulphide producers are sulphate-reducing bacteria and they are regarded as the main culprits of anaerobic corrosion (Stipanicev et al., 2013).

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2.2.1. Aerobic bacteria – sulphate-oxidising bacteria

Sulphate-oxidising bacteria are microorganisms which are capable of oxidising elemental sulphur or sulphur-bearing compounds to sulphuric acid (Vidyalakshmi and Sridar, 2007). Sulphate-reducing bacteria use sulphate as a terminal electron acceptor for the degradation of organic compounds, resulting in the formation of sulphide. This sulphide subsequently, can be oxidised by sulphur-oxidising bacteria to produce sulphate (Behera et al., 2014). The latter make sulphate available in soil through its oxidation process (Vidyalakshmi and Sridar, 2007).

2.2.2 Anaerobic bacteria – sulphate-reducing bacteria

Sulphate-reducing bacteria are most dominant under anaerobic conditions (wet clay, boggy soils, and marshes). One of the most important anaerobic bacteria that affect the corrosion behaviour is the sulphate-reducing types (*Desulfovibrio* sp.) (Shao et al., 2012), (Jiang et al., 2012). The presence of sulphide ion significantly affects the both anodic and cathodic reactions occurring on iron surfaces (Chen et al., 2014). The ion tends to hinder the cathodic reaction particularly the hydrogen evolution and accelerates anodic dissolution (Venzlaff et al., 2013).

The sulphate-reducing bacteria utilizes a wide range of spectrum of different low molecular organic compounds such as lactate, acetate, pyruvate, ethanol, sugars, which act as electron donors and also the supply of energy (Mudryk et al., 2000). The final product of the bacterial respiration process is hydrogen sulphide which will be released into the environment and facilitate the corrosion process (Videla and Herrera, 2005).

2.2.3 Sulfate-Reducing Bacteria and Corrosion

Sulfate-reducing bacteria (SRB) are non-pathogenic and anaerobic bacteria and it can act as a catalyst in the reduction reaction of sulphate to sulphide (Chen et al., 2014). The bacteria are able to make severe corrosion of metals in a water system by producing enzyme which can quicken the reduction of sulphate to H_2S. H_2S is known to be very corrosive (Venzlaff et al., 2013), (Wu et al., 2014). The enzyme stated to have accelerates the reduction of sulphate is called the biofilm.

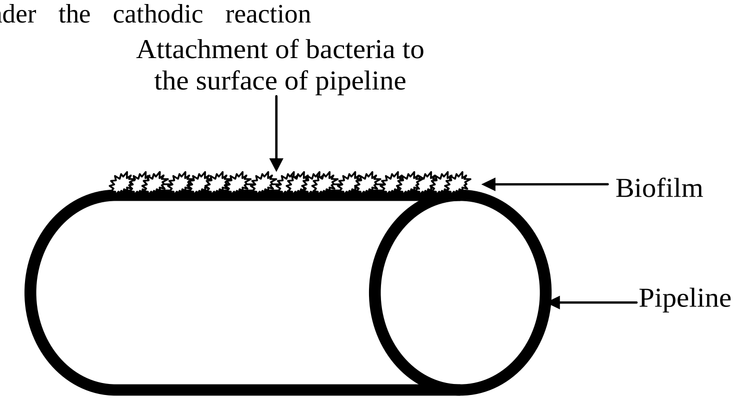

Figure 1: The inhabitation of bacteria on surface which produces biofilm.

ISSN Number: 2289-3946

Biofilm observed on the metal surface is an important factor for inducing the microbial corrosion (Zhang et al., 2011). The formation of biofilms on metal surfaces are the result of an accumulation process that starts instantly after metal immersion in the aqueous environment (Videla and Herrera, 2005). Observation of biofilm on surfaces shows a thick and black-coloured film consisting of corrosion products developed on the exterior of the pipeline (Javaherdashti et al., 2006). There are four steps of biofilm formation which are as follows:

i. Transportation of organic material to metal surfaces; organic material that serve as food to the bacteria would appear on the surface of the metal.
ii. Transportation of microbial cells from bulk to surface; free-floating bacteria will now anchor to the surface, inhabiting and coating the surface.
iii. Attachment of microbial cells; the cells of the bacteria will now start to produce slimy extracellular substances that is called biofilm.
iv. Growth within the biofilm; the bacteria will now reproduce and grow within the biofilm.

The reduction of sulphate to sulphide by the bacteria encourages the conditions for precipitation of iron sulphide which next catalysed proton/water reduction into molecular hydrogen and act as a cathode with the metallic iron (Chen et al., 2014). Moreover, the direct product of the bacteria metabolism, which is H_2S, can affect metal surface right by decreasing local pH and helping differential cell resulting with localized events on metal surfaces (Wu et al., 2014).

$$4Fe \rightarrow 4Fe^{2+} + 8e^{-} \qquad (2.1)$$

$$SO_4^{2-} + 8H^{+} + 8e^{-} \rightarrow HS^{-} + OH^{-} + 3H_2O \qquad (2.2)$$

Equation 2.1 shows the process of iron dissolution (Kakooei et al., 2012), where the electrons produced due to the reduction process helps supplies electron for the cathode (Shaw and Kelly, 2006). Equation 2.2 shows the cathodic half reaction of sulphate reduction from sulphate to sulphide due to biofilm catalysis. Species were added to balance the charges (Kakooei et al., 2012). Sulfate-reducing bacteria can make the SO_4^{2-} speed up corrosion and separate out hydrogen (Zhang et al., 2011).

Currently, sulphate reducers can be divided into two main groups; those that degrade organic compounds incompletely to acetate and those that degrade organic compounds completely to carbon dioxide (Muyzer and Stams, 2008).

3. Conclusion

Microbial Induced Corrosion is not generated solely by the role of microorganism. The process of microbial inhibition on the exterior environment of the pipeline facilitates the whole process of corrosion. Biofilm that results from the inhibition mediates the electrons of anode and cathode, which tend to fasten the process of corrosion. The new trends in research should focus more on how to mitigate or slow down the process of microbial inhibition on the pipeline which can stop or slow down the rate of biofilm production and how to control this matter through environmental friendly methods.

ISSN Number: 2289-3946

Acknowledgements

This paper was financially supported by Universiti Malaysia Kelantan (grant no. R/SGJP/A08.00/00880A/001/2014/000167)

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ISSN Number: 2289-3946