UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

THE EFFECT OF SEAWATER ON THE CORROSION BEHAVIOR OF NATURAL GAS PIPELINES IN MALAYSIA

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Master of Manufacturing Engineering

2013

THE EFFECT OF SEAWATER ON THE CORROSION BEHAVIOR OF NATURAL GAS PIPELINES IN MALAYSIA

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A thesis submitted
In fulfillment of the requirement for the degree of Master of Manufacturing Engineering (Manufacturing System Engineering) in Manufacturing Engineering

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2013

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the degree of Master of Manufacturing (Manufacturing System Engineering). The member of supervisory committee is as follow:

Dr Mohd Asyadi 'Azam Bin Mohd Abid

DECLARATION

I declare that this thesis entitle "**The Effect of Seawater On The Corrosion Behavior Of Natural Gas Pipelines In Malaysia**" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : **SUZIEE BINTI SUKARTI**

Date : ....

DEDICATION

To my beloved parents, Sukarti bin Sukimi and Siti Masrah binti Yusoff, all my friends.

Thank you for the continuous support and encouragement.

ABSTRAK

Air laut ialah kimia yang agresif secara semulajadi, cecair yang kompleks yang memberi kesan kepada hampir semua struktur bahan pada tahap tertentu. Kakisan dalam air laut adalah bergantung kepada beberapa faktor seperti komposisi bahan, sifat kimia air, pH, biofouling, organisma mikrobiologi, pencemaran dan suhu. Pemahaman terhadap faktor yang memberi kesan kepada karatan di dalam air laut dapat membantu rekabentuk bahan, komponen dan sistem untuk pengggunaan optimum dan hayat struktur bahan. Satu kajian telah dijalankan untuk mengkaji kesan perbezaan air laut di sekitar Semenanjung Malaysia ke atas keluli karbon yang berfungsi sebagai saluran paip bagi petroleum dan gas asli. Kaedah Extrapolasi Tafel telah digunakan bagi menilai kadar karatan keluli karbon dengan menggunakan air laut yang berbeza sebagai eletrolit. Dalam eksperimen ini, keluli karbon API 5L X42 telah digunakan dan air laut yang diambil adalah dari Laut China Selatan dan Laut Selat Melaka. Selain pengiraan kadar kakisan jenis karatan juga telah dibincangkan berdasarkan morfologi asas dan kandungan air laut juga ditentukan. Didapati bahawa kadar kakisan spesimen keluli karbon adalah lebih noble di Selat Melaka Laut daripada itu di Laut China Selatan. Variasi keputusan diperolehi iaitu diantara 0.10 -0.25 mm / tahun. Karatan jenis seragam dan setempat didapati menyerang permukaan spesimen dengan teruk. Kadar hakisan yang lebih rendah dicapai dengan kandungan natrium klorida dan pH yang lebih tinggi. Sebahagian daripada bahan yang larut seperti oksida ferum juga menyumbang pada pembentukan karat. Secara umumnya, Laut China Selatan adalah lebih baik bagi penggunaan bahan ini walaupun bahan ini boleh digunakan di kedua-dua jenis laut.

ABSTRACT

Seawater is inherently chemically aggressive, complex fluid that affects nearly all structural materials to some extent. Corrosion in the seawater is dependent on a number of factors such as material composition, water chemistry, pH, biofouling, microbiological organisms, pollution and contamination and temperature. Understanding how these factors may affect corrosion in seawater can support the design of materials, components, and systems for optimal service performance and structural life. A study was taken to investigate the effect of different seawater surrounding Peninsular Malaysia on the carbon steel having application as petroleum/natural gas pipeline. The Tafel Extrapolation technique has been applied to evaluate the corrosion rate of the carbon steel and different locations of natural seawater have been used as the electrolyte solution. In this experiment, Carbon steel API 5L X42 were utilized and the seawater is taken from the South China Sea and Strait of Malacca. Beside the corrosion rate calculating the type of corrosion attack has also been discussed on the basis of the morphology and the content properties of seawater are determined. It is found that the corrosion rate of the carbon steel specimen is significantly nobler in the Strait of Malacca Sea than that in the South China Sea. The results varied from 0.01 to 0.025 mm/year. Immersion test of two hours and ten days were carried out to determine the corrosion product that formed at the surface of pipe. Localized corrosion (pitting) and uniform corrosion attacked the surface specimen severely for each sea. The lower corrosion rate is achieved with higher contents of sodium chloride and salinity. Some of the dissolved material such as Iron oxide also distributes to the formation of corrosion. Generally, from the result, South China Sea is more favorable in the application of this material even though the material is acceptable in both seas.

ACKNOWLEDGEMENT

First and foremost i offer my sincerest gratitude to my PSM supervisor, Dr. Mohd Asyadi 'Azam Bin Mohd Abid for the advice and guidance. Besides, i would like to thank my parents, family, friends, lecturers, laboratory technicians and UteM staffs. Finally, i am really grateful to Universiti Teknikal Malaysia (UTeM), especially to faculty of Manufacturing Engineering (FKP) for providing me with all the knowledge.

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LIST OF ABBREVIATIONS

API	-	American Petroleum Institute
ASTM	-	American Society for Testing and Materials
ASME	-	American Society of Mechanical Engineers
A	-	Ampere
K	-	Kelvin
Kg	-	Kilogram
m/s	-	Meter per second
MIC	-	Microbiologically Influenced Corrosion
Mpa	-	Megapascal
Mm	-	Milileters
pH	-	Potential of Hydrogen
SCC	-	Stress Corrosion Cracking
TDS	-	Total Dissolved Solid
µm	-	Micronmeter
Fe	-	Ferum
H^+	-	Hidrogen Ion
Mn	-	Manganese
Al	-	Aluminium
P.P.T	-	Part per Thousand
N.T.U	-	Nephelometric Turbidity Units

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CHAPTER 1

INTRODUCTION

This section basically is an introduction to pipelines underneath seawater in Malaysia and problem statement for this research. The graphic illustrations can be found in the appendices.

1.0 Introduction

In recent years, since the first oil pipelines are embedded underneath sea using welded steel, the most common basic purpose of pipelines underneath sea still remains the same as the network for the fuel (oil/gas) transportation. The first cross-country pipeline is called PLUTO (Pipe Line under the Ocean) which is built during the World War II, since then the technology has improved, the undersea pipeline is a practical ways to transport water, fuel, oil and gases, therefore carbon steel or are commonly used.

Malaysia also has many companies that develop undersea oil and gas pipelines that have the capability to design, build, operate and maintain gas processing and transmission pipeline infrastructure around peninsular and east Malaysia. Natural energy problem, including environmental aspects had changed the character of pipelines underneath sea water. According to Institute of Engineering Malaysia (2003), Malaysia warm seawater is threatened by direct and indirect pollution sources. These changes that occurred undersea will lead to the pipeline corrosion and simultaneously have a tendency to degrade. Sea water corrosion involves reactions where the metal surface is transformed into metal oxides or hydroxides (like rust) (NDV, 2004). Apart from the natural energy problem and environmental changes, the rate of seawater corrosion depends on several factors like metal impurities, temperature, oxygen access, metallic contact (conductive) with dissimilar metals, sea water flow velocities, type of metals, surface protection and stresses.

Failure of submarine pipeline by corrosion has been a familiar phenomenon in processing plants resulting in unscheduled plants shut down, in consequences; there are heavy losses in industrial production and disruptions to civil amenities. A lot of research has been made to overcome the problem with underwater pipeline and its repair still remained a challenge.

1.1 Problem Statement

Corrosion is an electrochemical process which is the dissolution of the pipeline in the anodic areas as charged positive ions into the seawater or sea bed sediment. These ferrous ions react to form oxides and hydroxide and may form ferric salts if the water is well oxygenated. Palmer (2008) suggests that pipelines buried undersea ought to be an at least risk of corrosion because of the oxygen content should be low but the offshore pipelines become often acceptors of corrosion attack, which is enhanced by undersea biochemical factors. The concentration of salts in the environment and the local temperature affects the resistivity and pH value, hence, both the potential corrosiveness of the environment and the coating degradation behavior.

In addition if the seawater has the presence of high chloride or low sulfate levels then the pipelines are at higher than normal risk of corrosion as the corrosion products of iron will be more soluble. The activity of the sulfate reducing bacteria also alters with salinity and temperature. Salinity changes occur in shallow inshore waters in hot and warm climates (e.g. The south east of Arabian Gulf and Malaysia). A small change in this one of the parameters will change the corrosion rate considerably and when the corrosion products are not deposited on the steel surface, a very high corrosion rate of several millimeters per year can occur. (Nyborg, 2005).

The undersea corrosion issue is of great interest for organizations managing offshore networks for oil/gas transportation. Oil and gas supply companies, engineering consultants and inspection agents, pay a lot of money to cope with marine corrosion, developing inspection methods and prevention technologies to enhance the integrity of undersea pipelines. For example, PETRONAS has undertaken collaborative development with the Commonwealth Scientific & Industrial Research Organization (CSIRO) to develop a novel composite prepreg for use in underwater repair of pipelines, with the solution to be known as PIPEASSURE (Petronas, 2011). Knowledge acquisition from corrosion literature and expertise for marine facilities integrity management has been the focus of the research. Thus, knowledge based expert systems are designed and implemented by modifying computational methods and tools, which are mainly applied in investigating the industrial system failure. The effects of the corrosive action are metal loss, reduction of mechanical strength and thereof premature aging of the pipe segments.

1.2 Summary of Problem Statement

The problem can be summarized in three critical points:-

i. Influence of seawater on the corrosion piping is apparent nonetheless limited information exists on the variation of seawater effect on external pipeline corrosion surrounding Peninsular Malaysia

ii. The variation of seawater characteristic that keep changing due to several factors such as contaminations might present a different potential corrosion risk and variable rate of corrosion that can give major on safety, environmental preservation and the economics pipeline operation.

iii. The undersea pipeline corrosion is enduring studies that keep varying due to several factors of seawater variation environment.

1.3 Expected Findings

This particular study can give a better understanding of corrosion behavior which is important in controlling the pipeline corrosion in the seawater of Malaysia. The corrosion rate result of the effect of sea water of Peninsular Malaysia on carbon steel pipe API 5L X42 and the corrosion behavior will determine the root cause of the failure.

Furthermore can broad its application range and therefore promises a large economic impact. However, for subsea pipelines, literature reveals areas that might be further developed from the conceptual and methodological viewpoint. This is because the corrosion of underwater oil/gas pipes presents certain differences to that observed in other types of marine facilities (seawater injection systems, offshore platforms and risers, desalination pipes, etc.). Besides, the remedy of undersea pipeline segments is quite problematic, since inspection methods and rehabilitation, are more expensive to those of near sea surface equipment. Therefore, knowledge of corrosion attack explaining the physiochemical mechanism, as well as the complexity and synergy of the undersea corrosive factors (electrochemical) might be assessed, enabling further understanding on issues of offshore pipelines corrosion and integrity management.

1.4 Significant of Study

The study of corrosion behavior will be useful to give information regarding selecting the type of material for subsea piping/pipeline justification for changes in the seawater composition over time led to more aggressive conditions which is resulting in unacceptably high corrosion rate. In order to prevent unnecessary problems from the corrosion attack at the pipeline, prediction type of material can be investigated and will give sufficient protection to the pipeline system. The proper study of corrosion in undersea pipeline in Malaysia's seawater will eventually have a major impact on the safety, environmental preservation and the economics pipeline operation. The study will also serve as a future reference that can be promulgated and exploited for through existing corrosion researcher groups in the different district of peninsular Malaysia.

1.5 Research Objective

The objectives of this project are:-

i. To determine the seawater contents in the different locations of Peninsular Malaysia.

ii. To analyze the corrosion rate of sea water on the carbon steel in the different seawater surrounding Peninsular Malaysia.

iii. To observe the corrosion behavior that occurs on the surface of the pipeline.

1.6 Scopes

This research will cover:-

i. Identify the seawater contents from component that influence the life form and heavy metal solution based on the Department of Environment Malaysia (DOE) standard.

ii. Natural seawater was taken from seawater surrounding Peninsular Malaysia with sea water that nearby the oil/gas plant processing.

iii. The sea water was divided into two groups; South China Sea and Straits of Malacca Sea, since Malaysia is surrounded with the different seawater continent.

iv. Material selected is the minimum allowable pipeline for oil/gas industries that based on API standard – API 5L X42.

v. Heavy metal solution or ion parameters are based on the material composition.

vi. The corrosion rate of the carbon steel is based on the Tafel Extrapolation Technique and material is fully immersed during the experiment according to ASTM G1-90 and ASTM G102.

vii. The study focuses on the external surface of the pipeline.

viii. The corrosion behavior on the surface of the pipe is identified using Optical Microscope and Stereomicroscope.

ix. Immersed in the natural seawater to investigate corrosion behavior.

x. Coating selection and mechanical testing will not be covered during the experimentation.

CHAPTER 2

LITERATURE REVIEW

Literature is important as a reference and comparison in this thesis. The strong research report can provide a clear understanding of the relevant studies. This chapter focuses on research and theoretical analyses have been done before and are relevant to a study conducted

2.0 Introduction

This chapter introduces the variety of corrosion in the piping or pipeline system. The condition will be focusing on the corrosion behavior, corrosion measurement and oil/gas pipelines under the sea surrounding Malaysia only.

2.1 Types of Corrosion

According to American Society of Mechanical Engineers (ASME) corrosion may occur in all piping and for the undersea piping need much necessity. Corrosion is the ongoing damage of material by chemical reaction with its environment. Corrosion is a separate reaction process on a metal surface where the loss of metal and production of electrons in anodic areas and the consumption of these electrons in the cathodic areas.

The reaction process means that the electrochemical oxidation of metals in reaction with an oxidant such as oxygen. Rusting, the formation of iron oxides is a familiar example of electrochemical corrosion. This type of corrosion typically can create oxide(s) or salt(s) of the original metal. Corrosion can be divided into two type internal and external corrosion. According to DNV (2004), most common corrosion can be categorized as follows:

- **General corrosion** – Normally called a uniform corrosion because of the metal loss is uniform from the surface of the metal.
- **Localized corrosion** – This type of corrosion ensue when the metal surface is partly covered with protective film, high or stagnant flow rate. Localized corrosion is characterized by the formation of severely corroded regions separated by sharp steps from neighboring areas.
- **Stress-corrosion cracking (SCC)** – SCC results from the combination of corrosion and tensile stress that can damage the material by cracking (Kadry, 2008). For SCC to ensue, these conditions need to be considered:
  1) An effective environment develops on the pipe surface
  2) The pipe is susceptible to SCC
  3) A tensile stress of sufficient magnitude is present
- **Hydrogen Embrittlement (HIC)** – Hydrogen embrittlement consequences from the simultaneous co-deposition of the primary metal and hydrogen on the surface of the work piece (cathode). The hydrogen is available from the water in aqueous plating bath chemistries. Hydrogen co-deposition can occur in the plating process either during the actual electrolytic deposition or during the cleaning and acid pickles preceding the plating bath.
- **Erosion Corrosion** – Resulted from the combined action of chemical attack and mechanical wear (Callister, 2003). For erosion corrosion to occur, it involves the repetitive formation and the damage of the surface film.

2.1.1 External Corrosion in the Undersea

In external corrosion of undersea pipe, the overall rate of corrosion on the pipeline external surface is detected by the ratio of anode area to cathode area, the concentration of cathodic reactant and the resistivity of the local environment which determines the rate of transport of ions between the anodic and cathodic areas.

The external corrosion process is the dissolution of the iron of the pipelines in the anodic areas as charged positive ions into the sea water or seabed sediment. The higher the availability of the oxygen to the metal surface, the higher the potential rate of corrosion. Oxygen access to the bare metal surface increases as the temperature of the water decrease. Pipelines are at the high risk of corrosion in cold water moving at high velocity (Nybord, 2005).

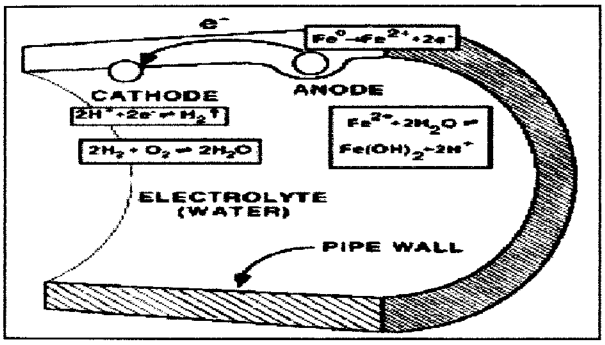

Figure 2.1 Electrochemical Reaction Occurring during Corrosion of Iron Metal in solution condition.

2.1.2 Formation of Corrosion with Seawater as an Electrolyte

In order to observe the formation of corrosion to ensue in the undersea, iron and steel is placed in the seawater and corrosion begin to form as a reaction in which the oxidation of metal is the anodic or corroding part of a corrosion cell. Chemical reactions at the anode involve the release of electrons and conversion of metal from a solid to an ion