EFFECTIVENESS OF HYBRID SOLIWAVE TECHNIQUE IN MITIGATION OF MICROBIOLOGICALLY INFLUENCED CORROSION

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This thesis is especially dedicated to,

My beloved family members: Hamidah Bte Abu Samah, Syed Hamzah Bin Syed Abd. Rahman and, Syed Hamizan, Sharifah Shazwani and Anis Farzana Azmiluddin.

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ABSTRACT

The applications of Ultraviolet (UV) radiation as an alternative approach to toxic chemical biocide for disinfecting bacteria such as Sulfate Reducing Bacteria (SRB) to mitigate Microbiologically Influenced Corrosion (MIC) in steel pipeline systems are already established. However, in the case of poor quality effluents, the UV radiation becomes less effective. Recently, Ultrasound technique (US) was observed to be attractive as pre-treatment for various types of physical disinfectant such as UV radiation. Hence, this research aims to investigate the performance of hybrid treatment known as Hybrid Soliwave Technique (HyST) to control MIC activity. The investigation was performed by utilizing two SRB strains namely pure strain ATCC 7757 and isolated SRB species from local site from BARAM, Sarawak. The study focused on three types of disinfection experiments which were individual UV radiation, individual US irradiation and HyST treatment, a combination of US and UV. Turbidity measurement and SRB cells were recorded to determine the most preferable pH and temperature for both SRB strain to proliferate actively. Corrosion rate was determined using weight loss method by exposing the steel coupons to SRB activity and abiotic sample. Both graphical and statistical analyses were performed using a statistical software (SPSS 20), to investigate the significance of SRB remaining cell number and SRB towards the corrosion rate of untreated and treated steel coupons. This study revealed that the preferable pH and temperature for ATCC 7757 and BARAM to grow actively in the Modified Baar's Media is at pH of 8.5 and temperature of 37˚C. While, the corrosion rate of steel coupons in ATCC 7757 and BARAM strain was 0.5058 mm/year and 0.3209 mm/year respectively. These rates were at least 44% higher as compared to the corrosion rate in abiotic sample (0.1791 mm/year). The treatment results show that the HyST treatment succeeded to reduce the number of active bacteria, hence reducing the corrosion rate by 55%. The results proved that the presence of SRB increased the corrosion rate significantly compared to samples without SRB. The present study also revealed that the HyST treatment is an effective and a feasible approach in substituting toxic chemical biocides in controlling the MIC problems especially for the pipelines. Overall, the HyST treatment shows better efficiency against individual UV radiation treatment.

ABSTRAK

Penggunaan sinaran ultralembayung (UV) sebagai kaedah alternatif kepada bahan kimia bertoksik bagi membasmi bakteria seperti bakteria menurun sulfat (SRB) untuk kawalan kakisan pengaruh mikrob (MIC) telah lama digunakan. Walau bagaimanapun, kualiti efluen yang rendah mengurangkan keberkesanan sinaran UV. Sinaran ultrabunyi (US) sesuai digunakan sebagai pra-rawatan untuk pelbagai jenis pembasmi fizikal seperti rawatan sinaran UV. Oleh itu, kajian ini bertujuan mengkaji prestasi rawatan hibrid yang dikenali sebagai *Hybrid Soliwave Technique* (HyST) bagi mengawal aktiviti MIC. Kajian ini menggunakan dua baka SRB iaitu baka tulen ATCC 7757 dan baka SRB tempatan dari BARAM, Sarawak. Kajian bertumpu kepada tiga jenis ujikaji pembasmian SRB iaitu rawatan sinaran UV dan sinaran US individu serta dan rawatan HyST yang merupakan gabungan radiasi US dan sinaran UV. Ukuran kekeruhan dan bilangan sel SRB direkodkan bagi menentukan pH dan suhu yang paling sesuai bagi kedua-dua baka SRB berkembang dengan aktif. Kadar kakisan ditentukan melalui kaedah kehilangan berat dengan mendedahkan kupon keluli di dalam sampel SRB dan sampel abiotik. Analisis grafik dan statistik telah dijalankan menggunakan perisian statistik (SPSS 20) bagi mengkaji kepentingan SRB dan baki sel SRB terhadap kadar kakisan kupon keluli sebelum dan selepas rawatan. Hasil kajian menunjukkan bahawa pH dan suhu yang paling sesuai bagi pertumbuhan aktif kedua-dua baka SRB di dalam media *Modified Baar's* ialah 8.5 dan 37˚C. Manakala, kadar kakisan kupon keluli bagi ATCC 7757 dan BARAM, masing-masing adalah 0.5058 mm/tahun dan 0.3209 mm/tahun. Kadar ini adalah 44% lebih tinggi berbanding sampel abiotik (0.1791 mm/tahun). Keputusan rawatan menunjukkan bahawa rawatan HyST berjaya mengurangkan bilangan bakteria yang aktif dan dapat mengurangkan kadar kakisan sebanyak 55%. Hasil kajian juga membuktikan bahawa kehadiran SRB boleh meningkatkan kadar kakisan berbanding sampel tanpa kehadiran SRB. Kajian ini juga menunjukkan rawatan HyST adalah sesuai dan berkesan sebagai pendekatan alternatif menggantikan bahan kimia bagi membasmi SRB untuk kawalan MIC terutama bagi saluran paip. Secara amnya, rawatan HyST mempunyai kelebihan berbanding rawatan sinaran UV individu.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

API	American Petroleum Institute
APB	Acid Producing Bacteria
ATCC	American Type Culture Collection
Fe	Iron
$Fe(OH)_2$	Iron (II) Hydroxide
H_2S	Hydrogen sulfide
kHz	Kilo Hertz
DNA	Deoxyribonucleic acid
EDS	Energy Dispersive X-ray Spectroscopy
EPS	Extracellular Polymer Substance
FESEM	Field Emission Scanning Electron Microscopy
IRB	Iron Reducing Bacteria
MIC	Microbiologically Influenced Corrosion
RNA	Ribonucleic acid
SiC	Silicon Carbide
SRB	Sulfate-Reducing Bacteria
SPSS	Statistical Package for Social Science
UV	Ultraviolet
US	Ultrasound
THPS	Tetrakis-hydroxymethyl Phosphonium Sulfate
HyST	Hybrid Soliwave Technique
^oC	degree Celcius
A	Area in cm^2
D	Density in g/cm^3

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Pipeline systems are commonly made from carbon steel and have an excellent safety record for facilitating bulk shipments of crude oil and natural gas to consumers all around the world. The properties of pipeline networks structures are susceptible to failure. Both underground and aboveground pipelines are affected by corrosion throughout their service life. Corrosion can lead to structural failure or loss of containment, costly repairs, lost or contaminated products, environmental damage, risk to personnel, and loss of public confidence. Corrosion is one of the leading causes of failures in onshore and offshore transmission pipelines, threatening pipeline integrity internally and externally.

Deterioration of onshore and offshore pipelines can lead to catastrophic failure such as pipeline leakage and explosion if wrongly managed. Of all the different origins of corrosion, microbial corrosion, also known as Microbiologically Influenced Corrosion (MIC), has been identified as one of the major causes of corrosion failures. MIC is used to designate corrosion due to the presence and activities of microorganism (Javaherdashti, 2008). This type of corrosion might

occur in environments that promote the growth of microorganisms, including the environments where corrosion would not be predicted and the rates of corrosion can be extremely high. Therefore, researchers and engineers' needs to know how to recognize and deal with MIC as it can have serious detrimental effects on maintenance costs and the integrity of pipeline structure.

1.2 Problem Background

Generally, onshore and offshore pipeline are susceptible to internal and external corrosion. Most of the offshore pipeline failures are attributed to internal corrosion which is more than 50% of the time compared to external corrosion (Chalker *et al.*, 2011). External corrosion is still an issue but is generally quite well addressed using good cathodic protection and coatings. The issues are more important and critical for deep water pipelines where designs are more complex, and inspection, monitoring, and repair are very difficult and costly. Deterioration of steel pipelines due to MIC is a major and serious problem, involving considerable cost and inconvenience to industry and to the public. Therefore, microorganism activity which influenced the corrosion process in pipeline should be controlled since corrosion is one of the major factors that can affect transmission pipeline structural integrity and reliability. In oil and gas industry, wide spectrum of bacteria has been studied but Sulfate Reducing Bacteria (SRB) are the most common enabler related to MIC that cause major problems in oil and gas industry (Jhobalia *et al.*, 2005; Little and Lee, 2007; Al-Abbas *et al.*, 2013).

Conventional technique in disinfecting microorganisms in oil and gas industry is through application of chemical biocides such as glutaraldehyde. Unfortunately, they have a negative impact on the environment and aquatic life as the toxicity properties of biocides tend to disturb aquatic life and pollute the environment. Additionally, after prolonged application, microbials may become

resistant towards the biocides or inhibitors thus creating a corrosive environment (Jhobalia *et al.,* 2005). From an economic view, application of biocides requires huge cost to disinfect microorganisms and also affect the health of consumers and professional users. Driven by these challenges, engineers and researchers have discovered and proposed non-hazardous techniques such as application of Infrared radiation, Ultraviolet (UV) radiation and Ultrasound (US) irradiation treatment as an alternative to replace biocides in disinfecting microorganisms. Past studies showed that UV radiation alone effectively disinfects microorganisms, however the efficacy of UV radiation is highly affected by the concentrations of the sample (Darby *et al.,* 1993; Narkis *et al.,* 1995).

In addition to UV radiation, Ultrasound irradiation treatments also have detrimental effect to inactivate wide spectrum of microorganisms. Unfortunately the US irradiation system alone requires high energy usage and the efficacy is affected when volume of treated sample is high (Hulsmans *et al.,* 2009). Both US irradiation and UV radiation have their own benefits and limitations in disinfecting microorganisms. The current trend indicates that researchers have put more effort into investigating non-hazardous technique on disinfecting SRB, as they agreed that MIC is a major and serious problem in oil and gas industry and the application of hazardous chemical biocides should be reduced or replaced with alternative non-hazardous techniques.

1.3 Research Problem

Reports around the world have confirmed that, some oil companies had their pipeline ruptured due to MIC. Sulfate Reducing Bacteria (SRB) is the predominant bacteria that promotes corrosion on steel structures under anaerobic environment. Melchers (2006) stated that the second phase of corrosion is more concerning whereby SRB is able to speed up the corrosion after anaerobic condition had been

established. Therefore, even if maintenance is done regularly, pipelines are still facing corrosion attacks due to corrosive environments that surround the structure (Peabody, 2001; Wang *et al.*, 2011). Throughout the world, up to the present time, the application of hazardous chemical biocides is the preferred techniques for controlling MIC activity in oil and gas industry. Unfortunately, the usage of hazardous chemical biocides gives various negative impacts. To date, considerable study on non-hazardous technique in disinfecting microorganisms (e.g: Sulfate Reducing Bacteria) as an alternative to hazardous chemical biocides had been conducted by many researchers. Existing techniques, for example by using UV radiation or US irradiation alone, has limitations that affect its efficacy in disinfecting microorganisms. Many researchers have suggested that combination of US irradiation treatment with other types of treatment (such as UV radiation) will give a synergistic effect in disinfecting microorganisms. However, the non-hazardous technique by combining the US irradiation with UV radiation in disinfecting SRB has not yet received sufficient analysis and study. Therefore, research related to investigating the performance and synergistic effect of combination treatment of US irradiation with UV radiation based on variation of time of exposure in disinfecting SRB from pure strain and local strain is significantly needed.

1.4 Research Aim and Objectives

The aim of the present research is to investigate the performance of hybrid treatment, also known as Hybrid Soliwave Technique (HyST), which is a combination of US irradiation with UV radiation for the inactivation of SRB to control MIC activity. To achieve the mentioned research aim, this study embarks on the following objectives:

1. To calculate the corrosion rate of API 5L X70 steel coupon due to SRB;
2. To determine the remaining SRB cell number due to synergistic effect of Hybrid Soliwave Technique treatment as a function of time;
3. To identify the relationship between rate of bacteria extermination by Hybrid Soliwave Technique Treatment and corrosion rate of API 5L X70 steel coupon.

1.5 Research Scope

This research consists of experimental work in laboratory to investigate the performance of HyST treatment to disinfect SRB in corroding pipeline at pilot scale. In terms of bacteria inactivation, it includes two types of SRB strain which are obtained from American Type Culture Collection with culture number ATCC 7757 (known as ATCC 7757) and SRB strain which were extracted from crude oil sample originated from offshore Baram oil and gas field situated in East Malaysia (known as BARAM). Experimental work for the determination of optimum environment for both types of SRB to grow actively was performed based on various pH and temperature in specific media. Corrosion study upon SRB activity was tested on actual carbon steel API 5L X70. The HyST simulation reactor consists of US probe system and UV lamp for disinfection purposes. HyST simulation reactor consists of US probe with frequency of 24 kHz and power output at 200 watt, while UV lamp with wavelength of 254 nm with power output at 10 watt was used in present study. The HyST treatment was performed in order to determine the remaining SRB cell number and corrosion rate reduction of carbon steel API 5L X70 due to synergistic effect of HyST treatment. Parameters such as wavelength of UV lamp and frequency of US probe were set to constant and the treatment experiment is based on various time of exposures. Finally, both graphical and statistical analysis were utilized to observe the difference in disinfecting performance between HyST and individual UV treatment upon SRB (ATCC 7757 and BARAM) inactivation and corrosion rate reduction.

1.6 Significance of Research

Recently, the use of certain hazardous chemical biocides to kill bacteria, for example in oil and gas industry, must be carried out with permission from the authorities concerned. This is because these chemicals are harmful to the environment and human health. Stringent regulations in using hazardous chemical biocides for disinfection purposes prompt researchers and engineers to invent and promote a benign or non-hazardous technique such as Ultraviolet (UV) treatment in mitigating microorganisms, specifically Sulfate Reducing Bacteria (SRB). However, UV treatment alone has its limitation in mitigating microorganisms. Past researches have proven that a combination of Ultrasound (US) irradiation treatment with other types of physical treatment such as UV radiation has synergistic effect in killing microorganisms when combined. The combination treatment of US irradiation with UV radiation is rarely found in mitigating SRB due to limited researches. If the combination treatment could mitigate SRB effectively, the outcomes of this research will illustrate the synergistic effects of US irradiation as a pre-treatment measure in terms of performance in killing SRB. Future works on the development of combination treatment related to financial and corrosion mitigation scheme can be properly designed, following the outcome of this research. In addition, the outcome of this research could assist engineers and pipeline operators in reducing or eliminating the usage of hazardous chemical biocides and improve the efficiency of individual UV radiation treatment.

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