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Effectiveness of Ultraviolet Light For Mitigating Risk of Microbiologically Influenced Corrosion in Steel Pipeline

M. K. F. M. Ali, N. Md. Noor*, N. Yahaya, A. A. Bakar, M. Ismail

Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author: norhazilan @utm.my

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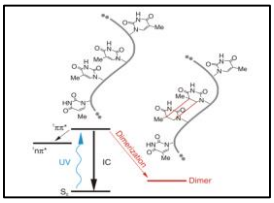
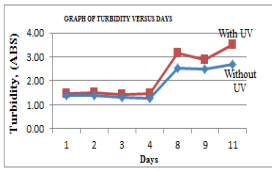
Graphical abstract





Abstract

Pipelines play an extremely important role in the transportation of gases and liquids over long distance throughout the world. Internal corrosion due to microbiologically influenced corrosion (MIC) is one of the major integrity problems in oil and gas industry and is responsible for most of the internal corrosion in transportation pipelines. The presence of microorganisms such as sulfate reducing bacteria (SRB) in pipeline system has raised deep concern within the oil and gas industry. Biocide treatment and cathodic protection are commonly used to control MIC. However, the solution is too expensive and may create environmental problems by being too corrosive. Recently, Ultraviolet (UV) as one of the benign techniques to enhance mitigation of MIC risk in pipeline system has gained interest among researchers. An amount of 100 ml of modified Baar's medium and 5 ml of Desulfovibrio vulgaris (strain 7577) seeds was grown in 125 ml anaerobic vials with carbon steel grade API 5L-X70 coupons at the optimum temperature of 37°C and pH 9.5 for fifteen days. This was then followed by exposing the medium to UV for one hour. Results from present study showed that UV radiation has the ability to disinfect bacteria, hence minimizing the risk of metal loss due to corrosion in steel pipeline.

Keywords: Corrosion; Sulfate reducing bacteria (SRB); Ultraviolet (UV)

1.0 INTRODUCTION

Pipelines play an important role in the transportation of oil and gases to consumers throughout the world. Pipeline structure must be durable and sustainable throughout service life time, whereby the cost of inspection and maintenance should not cause loss of profit margin. In the oil and gas industry pipeline operation and maintenance is always plagued by the corrosion issue. Since pipelines behave similar to other engineering materials which may and can fail due to corrosion, regular inspection and maintenance must be carried out. In response to great concern towards safety and environmental legislation a green inhibitor was investigated and created to combat corrosion problem in concrete structures [1, 2]. For pipeline structures non-physical inhibitors such as Ultraviolet radiation and Ultrasound treatment are viable options to replace while improving conventional methods using chemical biocides in controlling corrosion problem for pipelines. Destruction or deterioration of material due to the reaction with its surrounding environment is defined as corrosion [3] requiring huge cost for repair and maintenance to the industry. It is reported that the annual cost to oil and gas industry of maintenance for pipeline corrosion is estimated at $7.0 billion [4]. Hazardous materials are released due to corrosion of pipelines, tanks, storage units, and associated equipment which will increase the risk to the environment [5]. The presence of microorganisms which accelerate or decelerate corrosion activity is usually recognized as microbiologically influenced corrosion (MIC) [6]. One of the "*popular*" microorganisms that cause MIC in pipeline is known as sulfate reducing bacteria (SRB). SRB is well known because of its ability to reduce sulfate or sulphite ions present in the media to sulfide ions and undergo anaerobic corrosion [7]. SRB will introduce sulfide which is reduced form of sulfur and is highly soluble and reactive [8]. These bacteria are non-pathogenic and anaerobic in nature. They produce enzymes that have the power to accelerate the reduction of sulfate compounds to the corrosive hydrogen sulfide (H_2S). In other words, SRB acts as a catalyst in reduction reaction.

Chemical biocide treatments such as glutaraldehyde (GTD) and nitrate are commonly used to mitigate SRB in steel pipes [9]. Cathodic protection is also used to prevent MIC when it is used with coating [10]. However the used of biocides and cathodic protection techniques is very expensive and will cause environmental pollution [11]. Biocides can also cause environmental pollution in terms of chemical wastage and they are corrosive to metals [12]. The discovery of benign technique such as UV is under consideration as an alternative to biocides to mitigate SRB [13]. The main goal of this work is to identify the efficiency of UV in mitigating SRB in order to minimize the corrosion attack.

Corrosion is an electrochemical reaction between the metal and surroundings which produce corrosion products. Corrosion will occur due to surrounding such as air, water, acid and alkaline solution and also microbial reaction. In oil and gas industry corrosion is one of the major causes of failure in offshore structure [14]. Corrosion can be uniform corrosion, localized, or galvanic in addition to corrosion due to bacteria. This research focuses more on corrosion due to microorganism (eg. sulfate reducing bacteria (SRB)). Corrosion reaction needs reactive anode cell and inert cathode cell to occur. Oxidation occurs at the anode cell and reduction take place at the cathode cell. SRB influences the initiation of corrosion and oxidizes the organic matter or hydrogen for energy source [15].

Temperature is one of the factors that can influence the occurrence of corrosion and must be considered for bacteria to grow. As explained by Davis [16], the corrosion rate is higher when the temperature of sea water increased. Fontana [17] stated that the corrosion rate is getting higher when the temperature is increased in a closed system and corrosion rate is decreased when the temperature is increased for an open system as shown in Figure 1. Other than temperature, environmental element such as pH is considered as a factor for corrosion of metal to occur. Moreover, according to Stott [18], the pH range that is most suitable for the SRB to grow is 5-10. By considering temperature and pH, the suitable parameter for SRB growth can be determined.

Since UV radiation is found to be one of the benign techniques to disinfect microorganism [19], the present study is using ultraviolet (UV) radiation to mitigate SRB which is considered to replace the usage of biocides for controlling MIC in the future. UV light is defined as a portion of electromagnetic spectrum which lies between X-rays and visible light and in practical terms the application of UV disinfection depends on the germicidal ability of UV-C [20]. For best result, it is recommended to use UV with a radiation wavelength of 254 nm, which is in the germicidal UV-C spectrum [21]. UV radiation kills the microbial cells primarily due to its action on deoxyribonucleic acid (DNA). Once the DNA is destroyed the bacteria cannot be reproduced [22]. Figure 2 shows dimerization process of bacteria after being exposed to ultraviolet (UV).

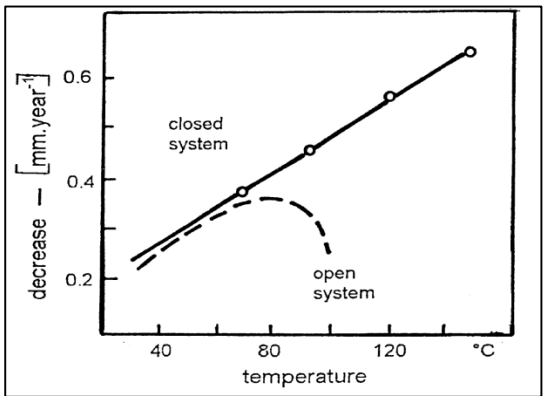


Figure 1 Effect of temperature towards metals corrosion in open and closed system [17]

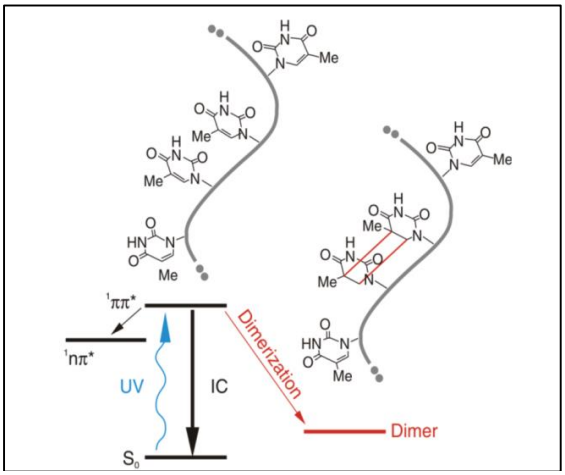


Figure 2 Dimerization process of *"Deoxyribonucleiacid"* (DNA) of bacteria [23]

Table 1 The components of modified Baar's medium

Component	*Composition*	*Amount*
Component 1	Magnesium sulfate.7H_2O, ($MgSO_4.7H_2O$)	4.096 g
	Sodium Citrate.2H_2O, ($C_6H_5Na_3O_7.2H_2O$)	5.700 g
	Calcium sulphate, ($CaSO_4$)	1.000 g
	Ammonium chloride, (N_4Cl)	1.000 g
	Distilled water	400.00 ml
Component 2	Potassium phosphate, (K_2HPO_4)	0.500 g
	Distilled water	200.00 ml
Component 3	Sodium Lactate	3.500 g
	Yeast	1.000 g
	Distilled water	400.00 ml
Component 4*	Ammonium iron(II) sulfate hexahydrate, 5% of $Fe(NH_4)_2(SO_4)_2$	

*Component 4 should not undergo autoclaved process, in which 0.1ml of this solution is added to 5.0 ml of medium prior to inoculation.

2.0 METHODOLOGY

2.1 Medium Preparation

Modified Baar's medium was prepared for SRB growth and composition of these media was listed in Table 1. An anaerobic environment for the SRB to grow was created by purging filtered nitrogen into the vials before autoclaving [24]. The prepared medium was then sterilized in an autoclave for 15-30 minutes as shown in Figure 3 at a pressure of 1.2 x 10^4 Mpa.

Figure 3 Sterilization process in an autoclave at a pressure of 1.2 x 10^4 Mpa

2.2 Coupon Preparation

Coupons were prepared by using carbon steel pipe grade API 5L X-70 (specimens were machined from the actual segment of pipe API 5L X-70 that was obtained from local gas operator). The coupons was refined by using 100 grit Si-C paper, which was cleaned and dried with ethanol to remove all form of dirt, grease and small Si-C particle on the coupon surface. The cleaned and dried coupons were then coated with prime coat leaving only the top surface exposed for the reaction of SRB towards the coupon. The coupons were dried overnight and the exposed area of the coupon was polished again with series of Si-C paper grade (320, 600, and 800), followed by acetone degreasing.

2.3 Calculation for Corrosion Rate, Cr

Steel coupons and the modified Baar's medium were prepared at standard pH and temperature (7.5 and 37ºC) based on American Type Culture Collection (ATCC) for the corrosion mitigation experiment. The anaerobic vials were filled with two coupons, 100 *ml* of Modified Baar's medium and 5 *ml* of SRB seed followed by incubation of the sample at temperature 37ºC for 28 days. Weight of coupons was recorded before and after the experiment to obtain the corrosion rate due to the reaction of SRB. Metal loss was determined by using *Equation 1* as the difference in weight of the sample was commonly used as a basis for calculating corrosion rate [25, 26]:

$$\textbf{Weight loss (W)} = W_o - Wa \qquad \textit{Eqn. (1)}$$

where;

W_o = Initial weight of coupon (g)
Wa = Final weight of coupon (g)

Additionally, by substituting *Equation 1* into *Equation 2* corrosion rate, Cr of steel coupon can be determined by using the formula of [27]:

$$\textbf{Corrosion rate, Cr} = \frac{k\,x\,W}{A\,x\,T\,x\,D} \qquad \textit{Eqn. (2)}$$

Where;

k (in mm/year) = 8.76×10^4
W = weight loss (g)
A = Area (cm^2)
T = time exposure (hours)
D = density of steel coupon ($7.86\ g/cm^3$)

2.4 Optimum pH and Temperature for SRB to Growth

Steel coupon sample and the modified Baar's medium (pH 6.5, 7.5, 8.5 and 9.5) were prepared to determine the optimum pH and temperature for SRB to growth. The process is similar according to the previous (e.g: corrosion rate,Cr) experiment except the sample was incubated at different temperature of 20°C, 37°C and 60°C for 15 days.

Optimum pH and temperature were recorded as a result for this experiment by using turbidity of medium as the reference for active SRB growth. Spectrophotometer DR 5000 was used to determine the turbidity of SRB in the medium.

2.5 Ultraviolet Disinfection

The above mentioned sample preparation was repeated with the optimum pH and temperature set at 9.5 and 37°C respectively. The filled anaerobic vials were exposed to ultraviolet radiation with wavelength 254 nm (exposed for 60 minutes) and the sample was left to incubate at temperature 37°C for 11 days. Weight of steel coupons was recorded before and after the experiment. The turbidity of the medium consisting of SRB was taken on a daily basis until day 11 by using spectrophotometer DR 5000. Serial dilution method was done to ease the measurement of turbidity of the medium. Figure 4 shows the instrument set up for ultraviolet disinfection and the disinfection process was conducted in a laminar flow.

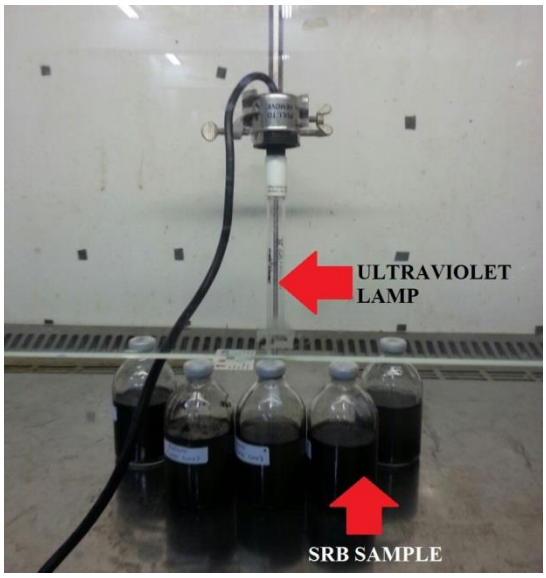


Figure 4 Ultraviolet disinfection instrument set up

2.6 Weight Loss Comparison

Medium sample with steel coupons and SRB was exposed to ultraviolet radiation and left incubated at temperature 37°C. The sample was retrieved from anaerobic vials after incubation period and steel coupons was cleaned with Clarke's solution to remove all form of dirt on steel coupon surface as shown in Figure 5 and Figure 6. The steel coupons were dried and the weight was recorded. The data obtained will be used to compare between weights of steel coupon before and after UV treatment.

■3.0 RESULT AND DISCUSSION

3.1 Corrosion Rate, Cr

Data of corrosion rate, Cr was recorded in Table 2 and the results showed that the rate of corrosion on steel coupon exposed to SRB activity were much higher as compared to steel coupon without SRB activity. The obtained result, showed the significant detrimental effect of SRB activity towards API 5L X-70 steel coupon. In an anaerobic condition the presence of SRB may increase the corrosion rate. In addition, the steel coupon can act as a secondary nutrient source for SRB to increase its metabolite rate and activity.

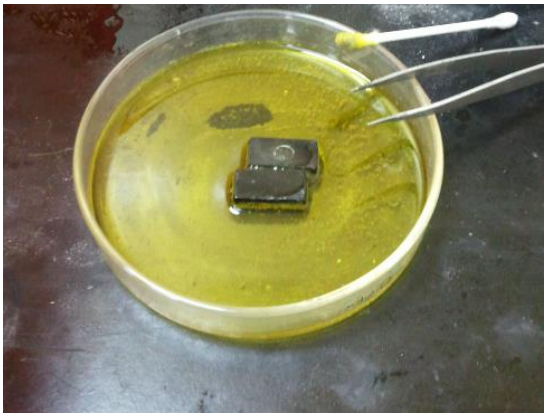


Figure 5 Coupon surface contains dirt before cleaning with mineral solution

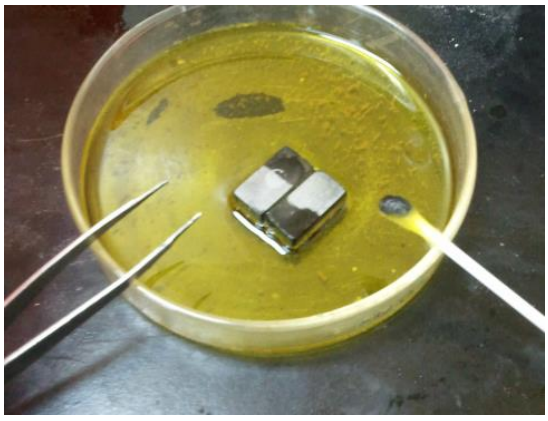


Figure 6 Coupon surface after cleaning with mineral solution

3.2 Optimum pH and Temperature

As shown in Figure 7, the graphs of turbidity against day were recorded daily until day 15 and the optimum pH and temperature are 9.5 and 37˚C respectively. The result reflects the study done by Postgate [28] and suitable temperatures for SRB growth is between 0°C to 75°C. Measuring the turbidity of medium is one of the methods to enumerate microorganism growth quickly. Increased turbidity of medium indicates high population of microorganism present in a medium. Experimental work in the present study in finding the optimum pH and temperature for SRB is crucial before treatment is done.

3.3 Result and Discussion of Ultraviolet Treatment

Figure 8 shows graph of medium turbidity subject with and without exposure to ultraviolet (UV) radiation treatment. The graph shows that the sample with UV radiation treatment resulted in low turbidity as compared to sample without UV radiation. High turbidity indicates the higher number of SRB population present in the medium. The characteristic of unpleasant odors from hydrogen sulfide and black colored solution are evidence of the presence of SRB and its metabolism in the medium [29, 30]. Hydrogen sulfide is a corrosive end product of SRB metabolism activity [31]. The UV radiation treatment can exterminate SRB and result in low turbidity in the medium. This shows that UV radiation has the ability to disinfect bacteria specifically SRB. Referring to Table 3, the amount of metal loss in samples without UV treatment was higher than the samples with UV treatment. The present study result reflects the ability of UV to disinfect microorganism or bacteria specifically SRB [32, 33]. Thus, the findings prove that ultraviolet radiation technique can be used to mitigate the corrosion subjected to SRB presence. Therefore, reduction of active SRB population can minimize the anaerobic corrosion and decrease the rate of corrosion towards steel.

Table 3 Data of weight loss with and without Ultraviolet (UV) treatment

With UV treatment		Without UV treatment	
Coupon no.	weight loss (g)	Coupon no.	weight loss (g)
A'3	0.0043	*A'12*	0.0850
A'15	0.0045	*A'26*	0.0582
A'22	0.0012	*A'28*	0.0729
A'40	0.0007	*A'52*	0.0680
A'45	0.0018	*A'60*	0.0203

4.0 CONCLUSION AND RECOMMENDATIONS

This study has shown that the optimum pH and temperature of particular SRB strain ATCC 7757 to growth was 9.5 and 37˚C respectively. Based on the laboratory works, it is reasonably well-defined that SRB can cause severe corrosion damage to carbon steel API 5L-X70. Environmental concerns have prompted researchers to find benign technique to mitigate MIC, other than fully depending on chemical and abrasive biocides treatment. The implementation of UV radiation for disinfecting SRB indicates that UV radiation can replace biocide usage as UV radiation is easier on the environmental than chemical biocide**.** Finally, a number of important limitations are needed to be considered as the results of UV treatment in this research were based only on static treatment. Further research can take into account the efficiency of UV treatment under dynamic condition. And finally, various voltage or intensity of UV usage can also be considered in future study.

Table 2 Corrosion rate (Cr) of steel coupon with and without exposed to SRB activity

	Corrosion rate, mm/yr	
Days	**Without SRB**	**Exposed to SRB**
7	0.146	0.202
14	0.071	0.131
21	0.050	0.161
28	0.074	0.365

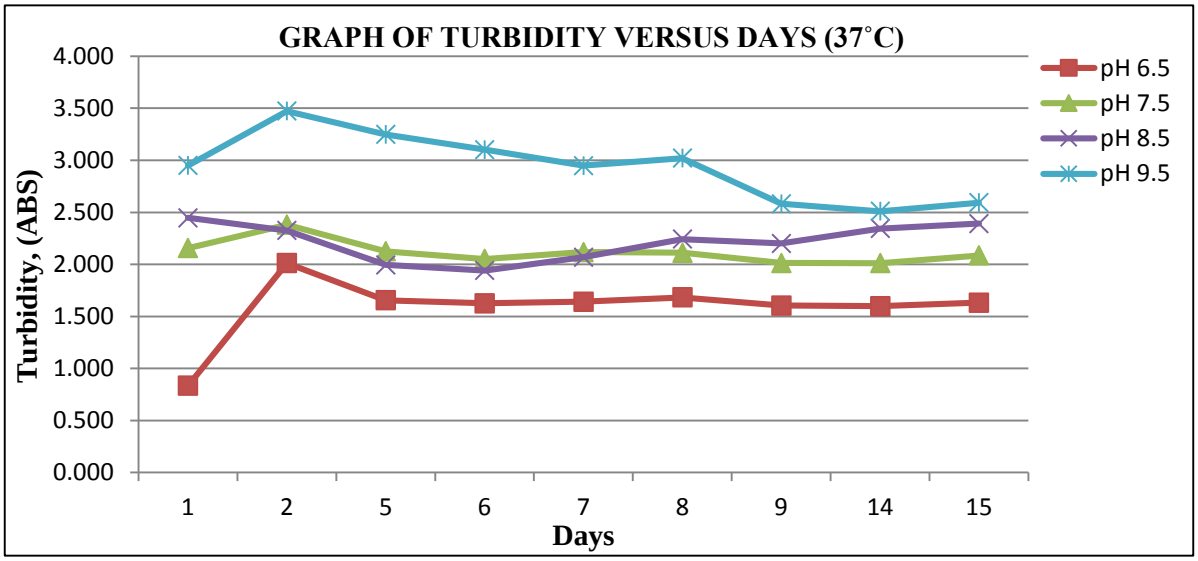


Figure 7 Graph of turbidity against days at 37˚C

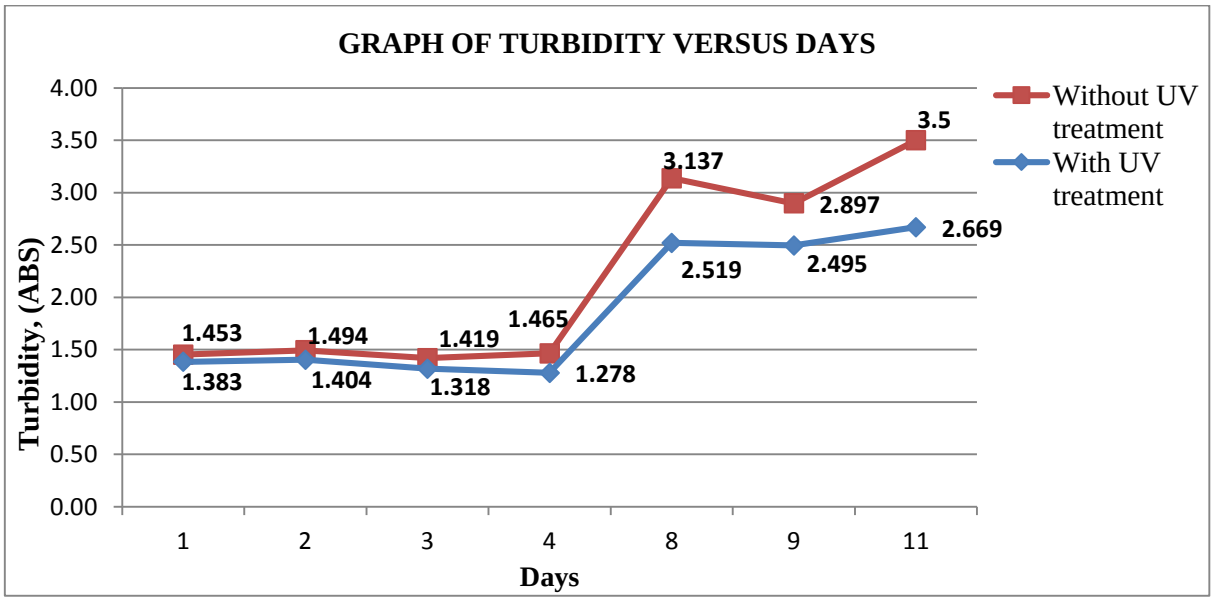


Figure 8 Graph of turbidity against day after UV treatment and without UV treatment

Acknowledgement

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