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Effect of Temperature in SRB Growth for Oil and Gas Pipeline

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Abstract

In the oil and gas industry, pipeline is the major transportation medium to deliver the products. MIC has been identified as one of the major causes of underground pipeline corrosion failure and Sulphate Reducing Bacteria (SRB) are the main reason causing MIC, by accelerating corrosion rate. The objectives of this paper is to study the SRB growth namely, *Desulfovibrio desulfuricans* ATCC 7757 correlating to one of the important environment parameter which is temperature. Thus, a determination of the optimum value for the parameter influencing the corrosion process on the internal pipe of carbon steel grade API X70 is unveiled. This research conducted via laboratory works and One-Factor-at-A-Time (OFAT) method is used for the analysis. The result shows that the SRB growth well at temperature ranging from 20°C to 37°C with the maximum exposure time of 28 days which produce the maximum Cr value of 3.746 mm/year at 37°C. The results in this study prove that the corrosion phenomena on carbon steel by the environment parameter such as temperature and time plays a role in the corrosion process. Furthermore, the study identified that the pitting type of corrosion is detected and accelerated at carbon steel pipe.

Keywords: Corrosion, MIC, Microorganisms, Sulphate Reducing Bacteria (SRB)

1. Introduction

Recent research studies on the relation of containment of pipeline loss indicate that corrosion is becoming one of the dominant failure modes for steel pipeline[1]. Carlos et al., 2008 stated that, biofilm growth on the surface of the steel pipe is rapidly accelerated when exposed to sea water[2]. As a result from the SRB attack, crude oil and gas industry was severely affected due to excessive production of sulfur that produced a sulfate that can cause of corrosion attack.

Therefore, the monitoring of corrosion due to this matter has become a great concern among the pipeline operators. In order to solve the problem, current practice by pipeline operators is by implementing Cathodic Protection (CP) and rehabilitation for external corrosion. However, for internal corrosion, it becomes more complicated tasks[3]. Monitoring on the external surface of pipeline is also easier compared to the internal pipe, thus require a continuous monitoring and specific tools for inspection. In order to address this problem an experimental study related to SRB growth conditions is conducted. From this, important parameters can be identified and prevention measures to control and mitigate the SRB growth can be done.

The aim of this research is to study the SRB growth, *Desulfovibrio desulfuricans,* ATCC 7757 due to the environment condition in terms of temperatures and to determine the optimum parameter influence the corrosion.

Temperature basically can affect the corrosion rate of steels in several ways. For example, the temperature accelerates the chemical reaction in the bulk solution and the electrochemical reactions at the metal surface by

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increasing reaction rates. Secondly, it also can speed up the mass transfer process by decreasing the viscosity of the solution. So if there are no protective films formed (especially at low pH). The increment of the temperature might also increase the general CO_2 corrosion rate[4].

Adding to that, at higher pH plus the increasing temperature can cause acceleration the kinetics of precipitation that aids the protective film formation. This condition provides a good anaerobic environment that helps the growth of SRB. Normally, the corrosion rate reaches a maximum growth with increasing of temperature at around 70 - 90°C[5]. This is attributed to the formation of a protective corrosion product film, $FeCO_3$.

The temperature effect on the corrosion rate is different for open system and closed system. In open system, the corrosion rate will increases in higher temperature, but the situation is different for closed system whereby the high temperature does not prove that the corrosion rate is increasing as well[4]. Thus, this research is conducted in a closed systems trying to prove that the previous notion on correlation of temperature and corrosion rate.

2. Experiment Test Parameter

In our study, the temperature becomes dominant test parameters by varying its value to determine an optimal significance for the bacteria growth. There are four temperature conditions that will be tested. The total numbers of coupon required is 40, plus another 2 extra coupons as a control coupon for each tested temperature.

The test parameter involved a number of batch experiment such as the pH as a constant parameter, exposure time in days, and variation of temperatures ranging from 20°C, 37°C, 60°C and 80°C. Details of the parameters used in the experiment are shown in Table 1.

2.1 Carbon Steel Pipe Coupon

Carbon steel pipe grade API 5L-X70 used in this study is a line pipe. The sample was cut from the original API 5L-X70 from oil and gas pipeline (Figure 2.) into a smaller

Table 1. Test parameter

Constant Parameter	Exposure Time (Day)	Variable Parameter
pH	7, 14, 21 and 28	Temperature : 20°C, 37°C, 60°C and 80°C

Figure 1. SRB bacteria growth in anaerobic vials for each parameter.

Figure 2. Carbon steel oil and gas pipeline grade API 5L-X70.

size approximately 10 mm x 20 mm size and the size must be in range 2.0 cm^2 and it call coupon (Figure 3). Coupon has been cut using wire cut.

The coupon has been cut and grinds to clean up the existing corrosion on the pipe faces. The grinder also used to grind the coupon edges. After grinding process the coupons were polish with a series of Silicon Carbide papers (SiC) grade 100 and 320. The polish process is conducted to make sure the surface of the coupons is free from scratches. This process is necessary in order to clean up all the existing corrosion, grease and any others debris because the sample was exposed to the environment.

All coupon faces are coated with zinc coating except for one because our scope of study only covers the corrosion at the internal pipe only. For each anaerobic vials, two tested steel coupons will be place (Figure 4). The anaerobic vials are spurge with oxygen-free nitrogen in

Figure 3. Carbon steel coupon before and after polishing.

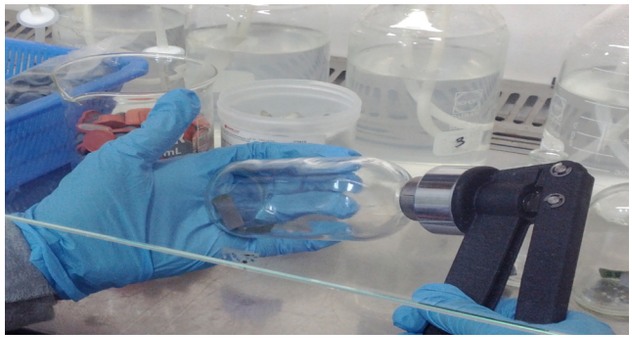

Figure 4. Clamping vials with coupon for anaerobic condition.

laminar flow hood to remove the oxygen inside it. Since the bacteria are an anaerobic organism, it can only survive and reproduce in the absence of the oxygen otherwise it cannot survive in the presence of oxygen.

2.2 Bacteria Medium Preparation

This research employed a laboratory SRB strain; *Desulfovibrio vulgaris* ATCC 7757 cultured. The cultured ATCC 7757 is in liquid form and the bacteria are obtained from *American Type Culture Collection* (ATCC). The medium is prepared according to ASTM E979-91 (ASTM, 2004). Table 2 shows a detail composition of the modified ATCC 1249 medium. The medium functions act as a food source, energy and provide a suitable environment for the bacteria to grow. Four bottle of medium are prepared for experiment, and pH for each bottle is constant at pH 7.5.

The medium shall be autoclave and after the autoclave process, all of medium bottle shall be inoculated with 97% nitrogen and 3 % hydrogen for an hour. The process must be done inside the laminar flow to ensure it is free from

Table 2. Composition of Simulated Pipeline Medium # ATCC

Component	Composition
Component I	$MgSO_4$, 2.0g Sodium Citrate, 0.5g $CaSO_4$, 1.0g NH_4Cl, 1.0g Distilled water, 400ml
Component II	K_2HPO_4, 0.5g Distilled water, 200ml
Component III	Sodium lactate, 3.5g Yeast extract, 1.0g Distilled water, 400ml
Component IV	Filter-sterilize 5% Ferrous Ammonium Sulfate $Fe(NH_4)_2(SO_4)_2$

*Note: The pH of component I, II and III is adjusted to the tested parameter and component IV does not need to be autoclaved, 0.1ml of this solution is added to 5.0ml of medium prior to inoculation.

the outside bacteria. The anaerobic bottle, medium and all the equipment used in the process has to be autoclave as well to make sure that our process is not contaminated. An autoclave is a device used to sterilize equipment subjecting them to high pressure saturated steam at 121°C for around 15–20 minutes.

After autoclave process, Ferrous Ammonium Sulfate ($Fe(NH_4)_2(SO_4)_2$) with 25ppm concentration are filtered into the medium, followed by an addition of sterile to the medium. An amount of 100 ml of the medium are then transfer to 125 ml of anaerobic vials under anaerobic condition. Two (2) ml of 1-day old SRB at 2.0 x 10^6 cell/ml was added for SRB inoculation (Figure 5). After the transfusion process completed, the anaerobic vial shall be incubated in an oven as a tested temperature. Readings of the progress is done each a day for 28 days. The turbidity and weight loss measurement is recorded for further corrosion growth rate analysis.

3. Testing Method

3.1 Measuring Corrosion Growth Rate

To determine the corrosion rate, metal loss measurement from the recorded experiment is used. This activity investigates the corrosion of iron assuming a uniform corrosion throughout the whole sample. This method measures the increase in the accumulating iron ion concentration in the test medium. The activity is completed with a calculation

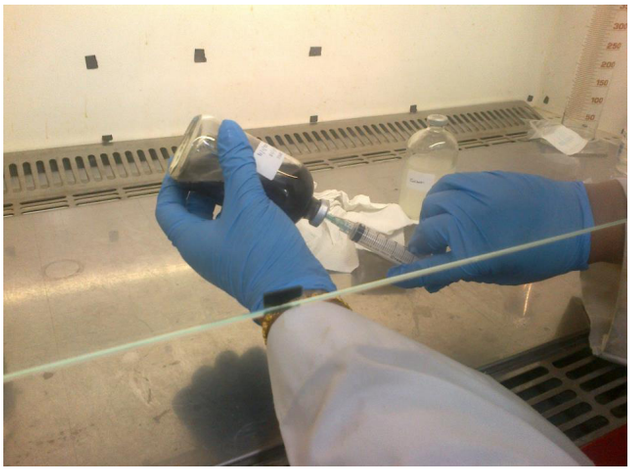

Figure 5. SRB transfusion process.

of the corrosion rate. Based on ASTM G15, Termology Relating to Corrosion Testing procedure, the uniform corrosion is defined as "corrosion that proceeds at about the same rate over a metal surface." This discussion stated that the uniform corrosion as equivalent material loss across the continuous surface of material.

The uniform corrosion type is further supported by Robert, 1996, which confirms that the methods conducted are not applicable to test specimen that show significant localized corrosion. The metal loss method is the simplest uniform corrosion test and expressed in metric units as millimeters per year (mm/yr). The metal loss test consist of preparing coupons, cleaning them before testing, weighing them before exposing them to the corrosion media, post-test removal of the visible corrosion product, and weighing them again. The corrosion rate is calculated from the metal loss measured before and after coupon exposure, converted to a volume of metal loss by the material density. Finally, the corrosion rate is calculated by dividing this volume by the material surface area and the test time.

Abrasive grit blast method is used for removal of corrosion products. The surface of the coupon is blasted until removal of all visible corrosion products is observed. After completion of the test, the corrosion rates are calculated from the mass loss as follows:

Corrosion Rate = (K x W)/(A x T x D) (1)

Where:

K = constant (8.76×10^4 for corrosion rate in mm/yr)

T = time of exposure, hour

A = area, cm^2

W = metal loss, g, and

D = material density, g/cm^3 (Refer to ASTM G 1)

3.2 Turbidity Test

Turbidity is a measurement of how cloudy water appears. Technically, it is a measure of how much light passes through water, and it is caused by suspended solid particles that scatter light. The medium should be diluted prior to turbidity experiment was conducted. The sample dilution was 10^1. Fill in 9 ml of distilled water into the tubes HACH at spectrophotometer and add in 1 ml of diluted sample medium. After the mixing process complete, the tube is inserted into the spectrophotometer to record the reading. Measurement of the turbidity unit is based on ABS (absorbance). As for the wave length testing, a single wave length at 600 Nm is applied.

4. Analysis and Results on Corrosion Due to Temperature, °C

4.1 Temperature Effects on Corrosion Growth Rate

This experiment aims to determine the optimum temperature for SRB growth and demonstrate the corrosion rate simulation using One-Factor-at-A-Time method (OFAT) method. Engineers and scientist often perform OFAT experiment, which vary only one factor or variable at a time while keeping others fixed[6]. To measure the corrosion of the coupon, weight loss technique has been used and the data is analyze using a graph.

Figure 6(a) illustrates that at temperature 20°C the maximum SRB growth is at exposure time of 28 days with percentage of weight loss of 24.025 % (0.24025 g). At day 21, the weight loss percentage is minimum which is 0.81 % (0.0081 g).

Figure 6(b) illustrates that at temperature 37°C the maximum SRB growth is at exposure time of 28 days with

Table 3. Weight loss % of sample with different temperature and exposure time

Exposure Time (day)	Weight Loss (%)			
	20°C	37°C	60°C	80°C
0	0	0	0	0
7	1.395	1.745	1.525	2.51
14	3.160	1.250	2.720	2.005
21	0.810	5.040	1.700	1.900
28	24.025	45.630	1.005	2.680

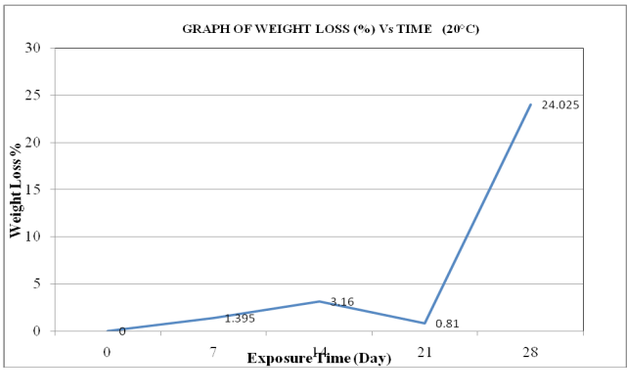

Figure 6. (a) Weight loss % at 20°C.

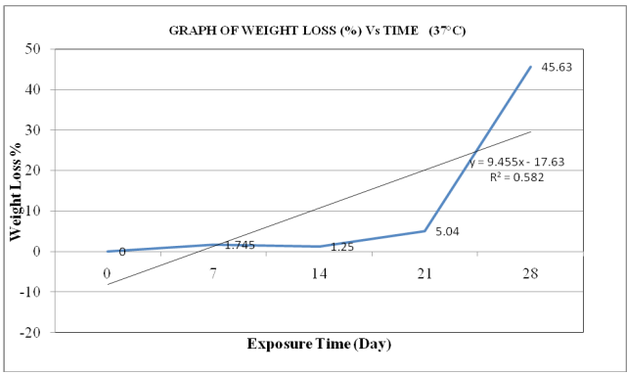

Figure 6. (b) Weight loss % at 37°C.

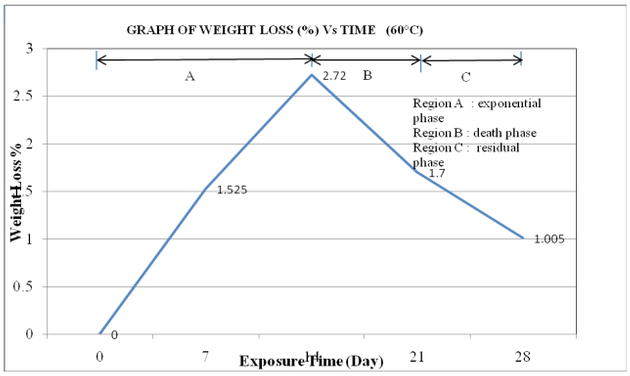

Figure 6. (c) Weight loss % at 60°C.

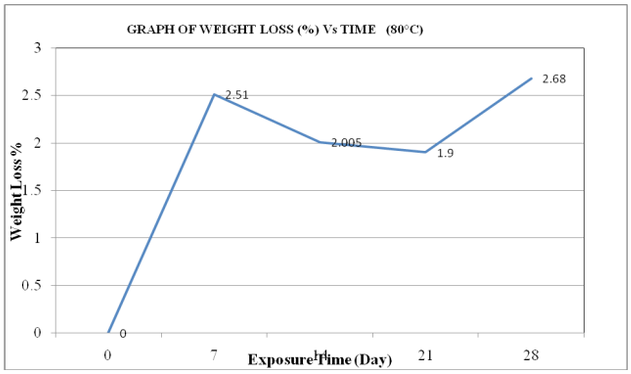

Figure 6. (d) Weight loss % at 80°C.

percentage of weight loss of 45.63 % (0.4563 g). At day 14, the weight loss percentage is minimum which 1.25 % (0.0125 g) is. The correlation coefficient, R^2 value of this graph is 0.582 (> 0.5) it's the correlation between weight loss % and exposure time is acceptable.

Figure 6(c) illustrates the result at 60°C. The result indicated that the growing process of SRB can be divided into three stages. 1 to 14 days is the 1st stage called exponential phase. During these stages, weight loss % increase quickly and achieve the maximum value at 14 days. After 14 days, the weight loss % decreasing at 2nd stage naming death phase. After 21 days, the weight loss % reach 3rd stage naming residual phase. During this stage the weight loss % is decreasing at a slower that stage 2. Comparing the % of weight loss at temperature 20°C and 37°C with 60°C, the % of weight loss at 60°C is much lower.

Figure 6(d) illustrates that at temperature 80°C the optimum SRB growth is at exposure time of 7 days with percentage of weight loss of 2.51 % (0.0251 g). The weight loss percentage is gradually decreased when the exposure time is increasing. Comparing the % of weight loss at temperature of 20°C and 37°C, the % of weight loss at 60°C and 80°C is much lower.

Figure 7 illustrate the weight loss % against tested temperature. The chart is to show the effect of temperature to bacteria growth. From the chart, the exposure time of 28 days give the maximum weight loss % at temperature range 37°C.

4.2 Effects of SRB Growth on Medium Turbidity

Medium turbidity experiment is to show the bacteria present and growth in sample medium. The turbidity not also detected the bacteria growth but also the chemical reaction within the cultured medium[7]. A spectrophotometer is used to determine medium turbidity (cloudiness) by measuring the amount of light that passed through a suspension of cell. The relationship between turbidity and suspension cell is: More cells = more turbidity; more turbidity = less light passing through the suspension. % T is transmission percentage which is the fewer cells present

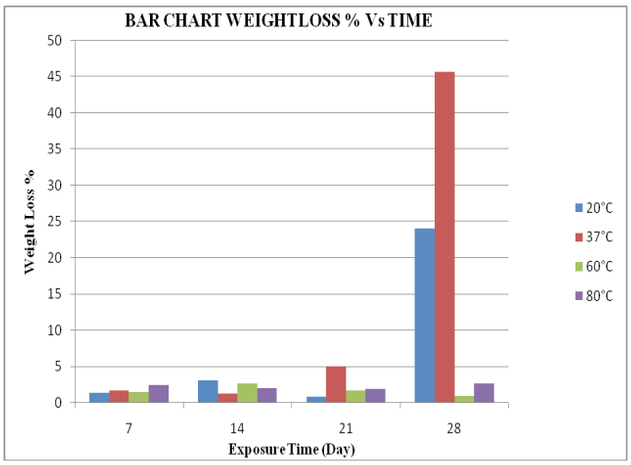

Figure 7. Bar Chart Weight loss % against exposure time at variable temperature.

(less turbidity) and will allow more light to pass through, the % T is higher when the cell number is lower. Absorbance is the opposite of % T. More light is absorbed when more cells are present. Absorbance goes up as turbidity (or cell number) goes up. Medium turbidity in this experiment is measured in absorbance units which are commonly seen as ABS. Table 4 is the result of medium turbidity.

Figure 8 illustrate the turbidity of medium against exposure time for tested temperature. The turbidity at 37°C is the highest and at 60°C gives the minimum turbidity reading. The control sample also shows the minimum reading of turbidity although the control sample not injected with SRB. The turbidity is not totally reflecting the bacteria growth but it shown there are the possibility of bacteria micro activity happen and the bacteria activity producing suspended cell.

As a conclusion, temperature is one of the most crucial factors affecting the growth of SRB. The results indicated that SRB growth within the particular temperature range. Finding in this experiment:

Table 4. Summary medium turbidity

Exposure Time (Day)	Turbidity (ABS) Control				
	20°C	37°C	60°C	80°C	60°C
7	2.159	2.871	0.602	0.560	0.416
14	1.911	3.500	0.460	0.552	0.43
21	2.002	2.202	0.482	0.598	0.395
28	1.969	2.391	0.492	0.699	0.375

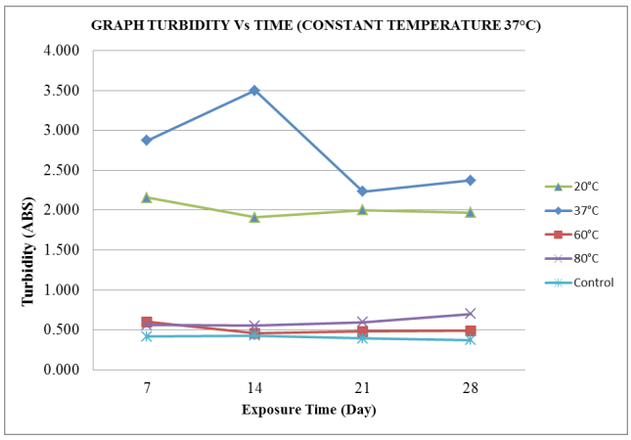

Figure 8. Medium turbidity at varies temperature against incubation time.

- The minimum growth temperature is 20°C and the optimum growth temperature is 37°C at which the % of weight loss is the highest.
- At temperature range 20°C - 37°C, the exposure time is increasing until reach the maximum growth at 28 days of exposure time.
- At 60°C and 80°C, the bacteria can still grow but at low rate.

5. Corrosion Rate (Cr) Derivation

Based on results of the experiments, the corrosion rate against exposure time graph is only tabulated for optimum parameter due to temperature, which is at 37°C.

Figure 9 illustrate the corrosion rate, Cr at different exposure time calculated based on Equation 1. The Cr

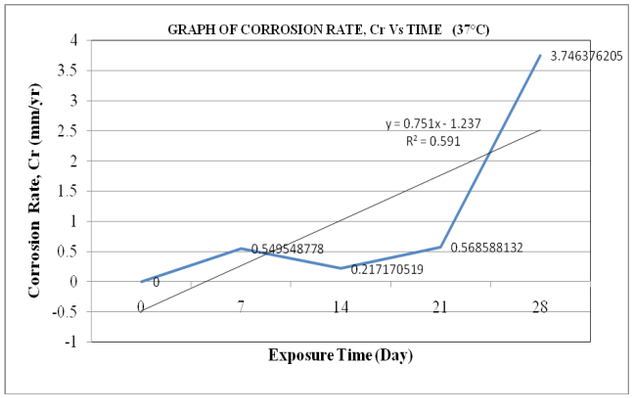

Figure 9. Corrosion rate against exposure time for temperature 37°C.

at 28 days shows the maximum Cr which is 3.746 mm/year and minimum Cr at 14 days which is 0.217 mm/year. Corrosion rate of 10 mm/year[8] in oil treatment plant and 0.7 mm/year to 7.4 mm/year due to SRB and/ or acid-producing bacteria in soil environment[9] have been reported.

Cr should be proportional to exposure time but at day 14, the Cr is dropping. This is maybe some of the bacteria are death and this will decrease the corrosion process. The change of the environment for temperature and the nutrient supply to bacteria might be the reason that effecting the growth of the bacteria. The correlation coefficient, R^2 for the graph is 0.591 (> 0.5).

6. Conclusion

SRB growth, *Desulfovibrio desulfuricans,* ATCC 7757 due to the environment condition in terms of temperatures proving of optimal temperature for the growth of SRB is 37°C.

7. Acknowledgment

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