

# Corrosion study of pipeline material for seabed sediment in tropical climate

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**Abstract.** Corrosive environments such as marine sediments can cause corrosion to steel pipelines at any time when certain conditions are met. Seabed sediment could cause severe corrosion damage due to its corrosiveness to the pipelines buried under it. Many consequences could take place in case if there is incident in oil/gas pipelines. Successfully identifying elements of corrosion in marine sediment would enhance the future of steel structure protection and monitoring systems. This article focuses on the behaviour of corrosion rate of steel located near shore environment and the aim is to determine the effect of sediment on corrosion of steel. To investigate that, simulated near shore sediment conditions have been used where the steel coupons buried in sediments which have different characteristics. Weight loss technique has been implemented to determine the weight loss rate of the steel specimens. Based on the results of this study, metal weight loss increases as the duration of exposure to seabed sediment environment become longer. The sea sediment simulated condition has given significant levels of corrosion. Conclusively, the corrosion rate of steel in seabed sediment located in tropical region is complicated and further studies are suggested.

## 1. Introduction

External corrosion is the main concern of the present research. One of the deriving motivations is the figure stated by [1] that the external corrosion accounts for roughly 38% of structural integrity problems faced by TransCanada pipelines Ltd. Besides that, in some isolated areas the pipelines experienced more than 50% wall loss [2]. Moreover, of the hazardous liquid pipeline accidents caused by corrosion, 65% were due to external corrosion and 34% were due to internal corrosion [3]. Furthermore, the major accidents reported to the U.S. Department of Transportation show that one quarter of Oil/Gas transmission pipeline systems accidents were due to corrosion. Out of that, for hazardous liquids, 65% of the accidents caused by external corrosion and 34% were due to internal corrosion, and the majority of gas pipelines accidents were due to external corrosion as well [3].



Pipeline failures are usually related to a breakdown in a system, e.g. the corrosion protection 'system' has become faulty, and a combination of covering soil, residual stress, temperature differential, and bending stress may lead to a corrosion failure [4]. Conclusively, external corrosion consequences and end results are highly important to be considered. Therefore intensive studies and close monitoring to the pipeline systems are required in order to move towards reliable prediction to remaining life of corroded pipelines.

Previously, it was generally considered that the corrosion of steel in sea mud was not serious. However, it was later found that the corrosion rate of steel in some sea mud was higher than that in seawater [5]. Currently research on marine corrosion by [6] has highlighted the severe effect of marine mud on steel. Using a corrosion index, [7] investigated and reported the corrosion of some stainless steels in a marine mud. The analysis showed the mud sediment to be very aggressive environment. Therefore, the objective of this study is to investigate the corrosiveness of seabed sediment in relatively controlled environment.

## 2. Methodology

This indoor investigation has been conducted to simulate the data from the site. The main difference between indoor and site is the controlled environment in the laboratory as compared to actual site. However the simulation has been targeted to reproduce similar results to those collected from the site. All steel specimens used in this experimental study were prepared from the actual pipe steel provided by an oil and gas company. Basically, the pipe used in this study is the same type of pipeline which been used by the gas company to transport gas from Segamat, southern part of Malaysia to Singapore. The pipes were cut into smaller segments to facilitate the transporting work of the steel material to the Structure and Material laboratory at Universiti Teknologi Malaysia. The steels that have been brought to the laboratory undergone preparation process to produce specimens to suit the progress of experimental work

### 2.1 Coupons preparation for weight loss experiment

The preparation of coupons for the experimental work has been done according to [8]. Firstly, the sections of the pipe in the laboratory have been reduced into smaller size in form of plates having approximate size of (200 x 350 mm). According to [8], the size and shape of test specimens are not rigidly defined. It is advisable to use the largest specimens permissible within the constraints of the test equipment. In general, the ratio of surface area to metal volume should be large in order to obtain maximum corrosion loss per specimen weight. Therefore, the plates further subjected to process of cutting them into smaller size as required for the experimental work. Steel coupons of size (60 x 40 x 5 mm) have been used for this laboratory works for the purpose of weight loss determination. Several researchers [9] [10] and [11] have used different sizes of specimens for corrosion testing.

Then, all the specimens subjected to milling process using the milling machine to remove the Fusion bonded epoxy (FBE) coating and corrosion product in order to produce uniform surface as shown in Figure 1. After that, hand grinder is used for grinding the coupons to further smoothen the surface of specimens. Towards the end of the preparation process, the specimens were cleaned, dried and stored in desiccators to prevent them from being exposed to corrosion.



**Figure 1:** Sample of coupon ready for experimental work

## 2.2 *Experimental method*

To study the corrosion and protection of marine steel, large steel plates were usually hung at the test site, which required much human and material resources and it was not convenient for necessary observations and measurements. In addition it was subjected to loss of experimental samples and test data caused by storms at sea. Furthermore, it is very difficult to measure directly the corrosion of steel in seabed sediment. Therefore, simulation test method that been designed to resolve problems mentioned above and could exactly reflect the universal corrosion law of offshore steel structure in marine environment has been used preciously [12]. Since laboratory simulation can simulate the seabed sediment corrosion environment with experimental equipment [13], this method has also been used to measure the corrosion rate of steel specimens. Hereby, the method was adopted to study the behaviour of steel specimens at laboratory and under controlled condition. Sufficient number of steel specimens has been located to carry out the investigation of corrosion factors in sediment. The number needed for each component of laboratory testing will be mentioned in the next sections according to the method of testing.

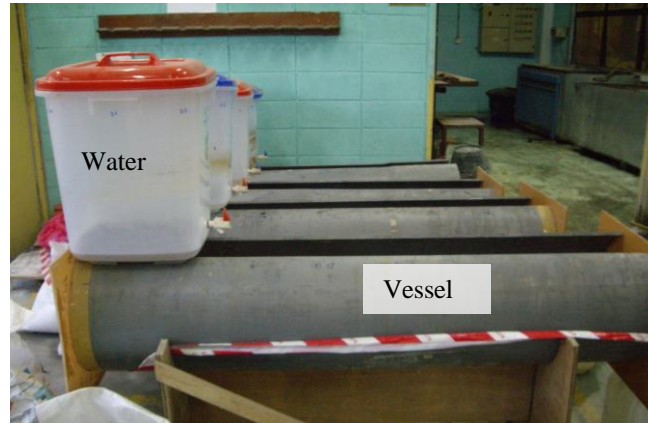
## 2.3 *Samples of seabed sediment*

Samples of sediments have been collected from all sites to represent each site at laboratory. Sampling instrument was used to gather enough quantities of soils to carry out the investigation at laboratory. The size of the container is determined by the volume of soil required for the test. A minimum of 40 cm<sup>3</sup> were used for each 1 cm<sup>2</sup> of exposed metal surface area calculated according to [8]. According to [8], the number of scheduled periodic specimen removals during the test should include duplicate and, preferably, triplicate specimens for any given test period to determine the variability in the corrosion behaviour. Therefore, four coupons were prepared for retrieval every month. The quantities of soil were calculated for the number of 21 coupons used in each vessel for weight loss determination. Overall 84 coupons were used for four sites simulated at the laboratory resulting at least with 170,000 cm<sup>3</sup> of sediment. Along with sediment samples, sea water and river water are collected as fresh medium to simulate the actual site condition in the laboratory. The water level in the vessels was maintained to cover the whole surface area of the sediment.

## 2.4 *Corrosion testing vessels*

The corrosion test vessel is plastic container with a siphon and a control valve. The container that used to store sea water has been fixed at higher level than testing vessel, to enable sea water to flow into the vessels replacing the used water with fresh water. The tank has seabed sediment to a certain height covered with sea water to simulate the closest possible real site condition. The seawater storage container designed to be a rigid and inactive container with outlet and valve, and connected to the tank, similar method that has been used by [12]. He used this method to simulate sea environment zones including atmosphere zone, submerged zone, tidal zone, splash zone and seabed sediment zone. The

method used intensively to study the seabed sediment alone. The corrosion testing vessels used in this study is illustrated in **Figure 2**.



**Figure 2:** Vessels used to place different sediments

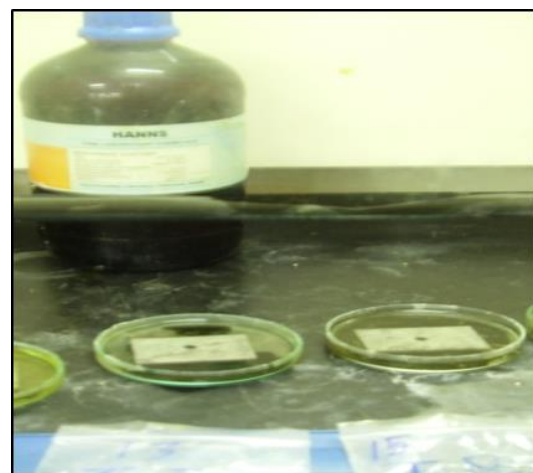
The four vessels have been used into each of them placed different sediments with different condition. Sea water was filled and covered the soil up to 200 mm above the soil surface to simulate the actual environment, the sea water was changed periodically and the temperature and other parameters in the tank have been measured simultaneously.

**2.5** *Cleaning procedure of corroded specimens*

Weight loss method was used to calculate the corrosion rate and the progress of metal loss experienced by the coupons as a function of time. After the retrieval of coupons which have been subjected to sediment environment, coupons undergone of cleaning process, Figure 3 shows coupons after normal cleaning. This process of cleaning was applied for all steel specimens. The retrieved coupons were rinsed and gently scrubbed under distilled water to remove adherent soil. Then, the chemical cleaning procedure as described in [14] was used to remove the remaining impurities leaving the bare coupon in Figure 4. Coupons were weighed repeatedly until it reaches its constant weight.



**Figure 3:** Coupon after retrieved from sediment



**Figure 4:** Chemical cleaning of coupons

**2.6** *Chemical solution preparation*

It is desirable to scrape samples of corrosion products before using any chemical techniques to remove them. These scrapings can then be subjected to various forms of analyses, including X-ray diffraction to determine crystal forms. These methods of scraping and chemical cleaning have been adopted from

[14] which covers procedures for preparing bare solid metal specimens for tests, for removing corrosion products after the test has been completed, and for evaluating the corrosion damage that has occurred. However care may be required so that uncorroded metal is not removed with the corrosion products when scraping the samples. The chemical technique that is discussed here tends to destroy the corrosion products and thereby lose the information contained in these corrosion products.

2.7 Corrosion rate calculation

The corrosion rate (mm/y) from metal loss is obtained using the [14] formula as follows:

$$CR = \frac{K * W}{D * A * T} \tag{Eq.1}$$

Where:

CR = Corrosion Rate (mm /y)

W = Weight loss in milligrams

D = Metal density in g /cm<sup>3</sup>

A = Area of sample in cm<sup>2</sup>

T = Time of exposure of the metal sample in hours

3. Metal loss of steel in simulated near shore sediment

In this experimental work, near shore environment was simulated to represent similar condition to the site, specifically focusing on metal loss behaviour of steel specimens due to exposure to near shore sediment. Herein, the sediments which have been collected from different sites with dissimilar properties are used in the laboratory to study the metal loss behaviour. The purpose of this simulation is to find a way to study and monitor the specimens more closely and to enrich the data besides the data collected from the site. **Figure 5** shows a graph of metal loss (in gram) for four different sites; Permas Jaya, Sungai Kim Kim, Batu Layar and Teluk Ramunia, representing the behaviour of steel corrosion in near shore simulated conditions. It can be seen from the graph that all sites show lower metal loss in the first month that are 0.160 g in Permas Jaya, 0.136 g in Sungai Kim Kim, 0.094 g in Batu Layar and 0.113 g in Teluk Ramunia. The result shows the metal loss increases gradually from time to time and at the end of six months. As presented in **Figure 5**, the metal losses are 4.238 g, 2.371 g, 0.825 g and 1.633 g in that order at the respective locations. The results presented in **Figures 6 to 9** show the behaviour of metal loss of each type of sediment in greater details. Monthly retrieval of steel specimens was considered for a period of six months to cover the early stage of metal loss for each condition.

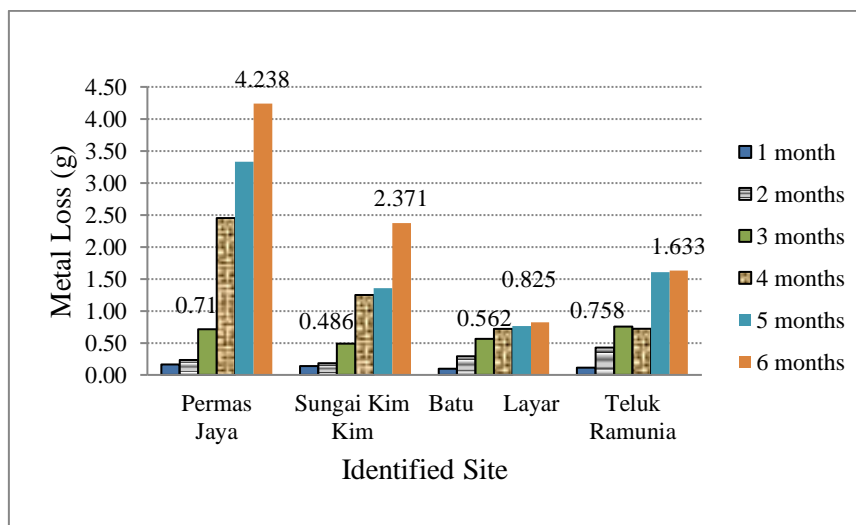
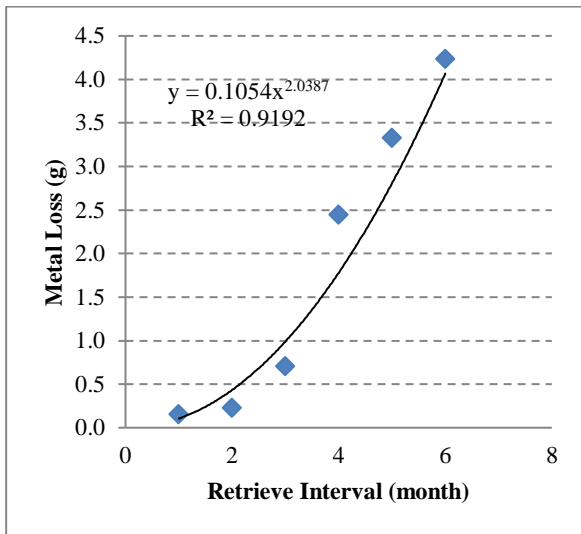
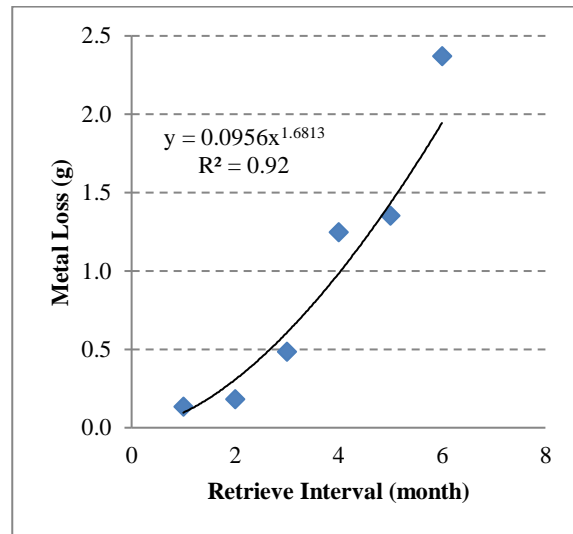


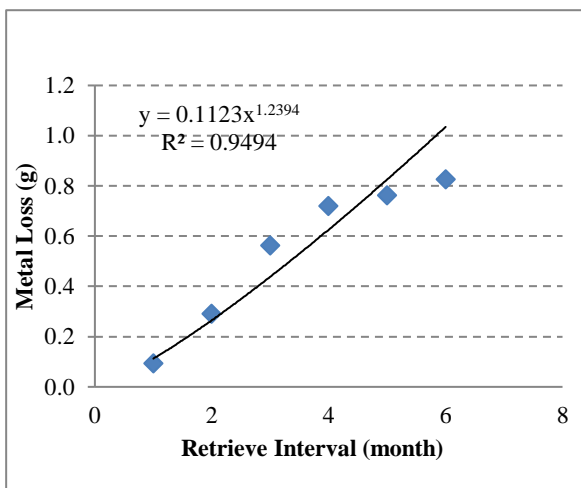
Figure 5 Metal loss of coupons tested at laboratory in sediment samples collected from four sites.



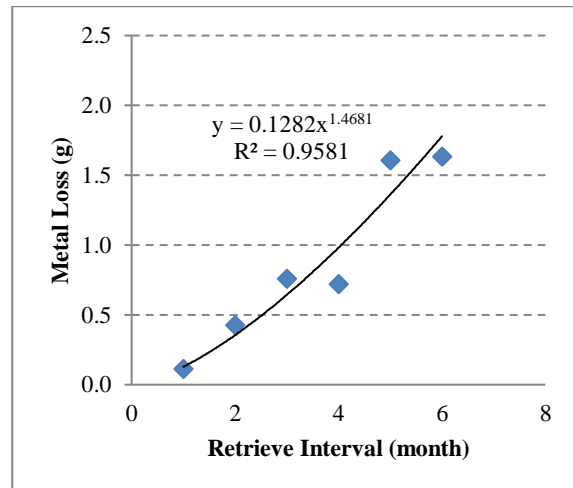
**Figure 6:** Metal loss for Permas Jaya sediment



**Figure 7:** Metal loss for Sungai KimKim sediment



**Figure 8:** Metal loss for Batu Layar sediment



**Figure 9:** Metal loss for Teluk Ramunia sediment

The results of this study show that the behaviour of metal loss is increasing with the time of exposure although the results are different from one site to another in terms of the average metal loss values. As it can be seen in **Figures 6 to 9**, the laboratory studies were limited to six months. However, the results are still reasonable to certain extent. For example, the results obtained at three months show that the metal loss is 0.486 g metal loss at the laboratory. The highest metal loss was obtained at Permas Jaya sediment for laboratory after six months exposure. This finding enhances the possibility to simulate the real environment at laboratory. It should be highlighted that the limitation of recent study to simulate exactly every aspect of the site in terms of daily changes of weather conditions e.g. temperature or humidity. Nevertheless, the simulation at the laboratory will indicate generally the behaviour of corrosion rate. The specimens were retrieved more frequent as compared with in-situ retrieves which normally takes longer intervals for each retrieve. Shorter retrieval time enables closer monitoring to the specimens and provides clearer ideas of exposure condition.

**4. Discussion of the results:**

Positive relationship between soil texture and corrosivity has been reported in the literature [13] reported that the corrosion rate in mud for three types of steels to be less aggressive than sand. On the other hand, [15] highlighted the mud to be more corrosive than loam and sand. However, findings of current study



provide support and explanation for some of the previous research. This is possibly because of organic and microbial influences which presented at site more actively than laboratory simulation. Microbial influences cannot be predicted from short-term laboratory observations, even if natural seawater is used [16]. This statement could provide further support to the results of current study. The differences might be explained in part by knowing that the mud which attached closely to each other and to the steel specimens besides the depth of water makes it difficult for oxygen to break through to the steel. That is could lead to lower corrosion rate as compared with sand. Nevertheless, it is known that bacteria and some of organisms become active in the absence of oxygen hence dissolved oxygen could prevent bacteria to grow [5]. Therefore, at sea mud with the absence of dissolved oxygen, which is the reason for bacteria to be active causing corrosion to be active and metal loss to be higher than other types of sediment. Corrosion under anaerobic environment can even make marine pipes perforated [13]. The presence of sulphide indicates the existence of sulphate reducing bacteria. This is supported by [17] who conducted sulphate reduced by bacterial enzymes would produce sulphide. Conclusively, simulation can be conducted, and it is relatively reliable to explain some corrosion phenomena for the short period of corrosion study. While for long term it's less accuracy for obtained results. Besides the difficulties facing laboratory simulation, the survival of organic and bacteria inside laboratory are limited. In the literature, some studies have been conducted indoor, however all are for short period of time [18]; [12]. On the other hand, long term researches have been conducted outdoor in the real environment.

## 5. Conclusion:

Conclusively, the corrosion rate of steel in seabed sediment located in tropical region is complicated. This most likely due to the difference in sediment parameters such that; the electrochemical factors and chemical constituent as well the microbiological influencing factors. The conclusion was derived based on qualitative judgment through observation on the metal loss volume and measurement. Other factors that may contribute to the variation of metal loss are the amount of organic content, the existence of Sulphate reducing bacteria (SRB) in anaerobic condition.

Based on this study, metal weight loss increases as the duration of exposure to seabed sediment environment become longer. However, the behaviour of corrosion growth rate in sediments has shown deferent pattern according to the condition. In most of the conditions, corrosion rate trends follow the weight loss trends. Generally, the corrosion behaviour in seabed sediment is complex. The metal loss of specimen located in near shore area signifies the corrosiveness of near shore environment.

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