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The Relationship between Soil Resistivity and Corrosion Growth in Tropical Region

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Abstract

Soil resistivity influences the corrosion of metals installed underground and can serve as an indicator of soil corrosiveness. From corrosion engineering perspective, the lower the resistivity, the higher the corrosivity and vice versa. Soil resistivity is most often measured using Wenner four-electrode method and resistance meter. The aim of this paper is to evaluate the influence of soil resistivity upon metal loss as experienced by corroding steel coupon. The steel coupons were installed underground for duration of 12-months at five different sites in Peninsular Malaysia. Results show that a negative correlation represents the relationship between soil resistivity and corrosion rate. Negative logarithmic model gives the best correlation among corrosion rate and soil resistivity. It also reveals that the relationship is time dependent whereby the longer the steel coupon being exposed to underground environment, the better the correlation. The outcome indicates that the measurement of soil resistivity can act as an early indicator of the potential of corrosion growth rate.

Keywords: Corrosion, pipeline, soil resistivity.

1. Introduction

Underground steel structures such as utility piping, pipeline, tanks and pilings placed in direct contact with soil environment are prone to corrosion attack. The often used method in the previous practice of corrosion protection for underground pipelines was to increase the wall thickness of the pipeline. The main reason of increasing wall thickness is to prolong the life span of the pipeline when subjected to corrosion in soil. The factors that influence corrosion in soil including oxidation-reduction (redox) potential, electrical resistance (resistivity), soluble ion content, pH, moisture content, rates of microbes in soil and many more. Most of these factors can be empirically measured to determine soil

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corrosivity [1-3]. The complexity of electrochemical process in soil may influence the steel pipe to corrode due to the presence of different soil electrolytes [1]. Li [2] added that the relationship among physicochemical parameters and soil corrosiveness is very intricate; therefore, the soil corrosiveness evaluated by these parameters is often undependable [3]. Hence, further development of existing methods for the study of soil corrosivity is essential.

Soil resistivity is one of the main factors that closely related to underground corrosion. As mentioned by Wilmott and Jack [4], it is believed that as soil resistivity becomes lower, for example: groundwater becomes saltier and more conductive; corrosion of a buried metal becomes more severe. Soil resistivity is a function of soil moisture and the concentrations of ionic soluble salt; hence it is considered to be the most comprehensive indicator of soil's corrosivity. The lower the resistivity, the higher the corrosivity as indicated in Table 1. According to a study done by Paillet *et al.* [5], many factors are correlated to soil resistivity such as salinity and nutrients [6], water content and preferential direction of water flow [7], texture-related properties such as sand, clay, depth to claypans or sand layers [8], bulk density [9], and other indirectly measured soil properties such as organic matter [10]. Therefore, soil resistivity can be a non-invasive means of measuring and mapping soil properties without intensive sampling campaigns [11]. In the other word, soil resistivity represents some major corrosion related soil properties, hence may serve as a good indicator for soil corrosivity.

Table 1: Soil corrosivity ratings based on soil resistivity [12].

Soil resistivity (ohm.cm)	Corrosivity rating
>20,000	Essentially non-corrosive
10,000 to 20,000	Mildly corrosive
5,000 to 10,000	Moderately corrosive
3,000 to 5,000	Corrosive
1,000 to 3,000	Highly corrosive
< 1,000	Extremely corrosive

Several predictive models have been developed [13-15] to predict corrosion process of underground steel structure. Many of these models integrate soil resistivity measurement in the calculation as well as soil and pipe characteristics. Velazquez *et al.* [15] has developed a statistical model from a total of 259 soil and pipeline samples for onshore underground pipelines operating in southern Mexico. The study shows that the failure of underground oil and gas pipeline is most likely due to leakage cause by external pitting corrosion. This type of failure is difficult to model on the basis of electrochemical reactions. Therefore, development of predictive models for pit growth was introduced mainly using statistical approach instead of electrochemical approaches. The model takes into consideration the chemical and physical properties of the soil and pipe to predict the time dependence of pitting depth and rate.

In year 2009, Caleyo *et al.* [14] combined a predictive pit growth model with the observed distributions of the model variables in a range of soils. The probability distributions of the pit depth and pit growth were investigated using Monte Carlo simulations. Alamilla and Sosa [16] developed a stochastic model for corrosion damage evolution. In this model, the probability distributions of corrosion depth and corrosion rate at given time are estimated analytically from the empirical probability density function of corrosion damage depth, the number of detected corrosion features and the distribution of the time of corrosion nucleation. The authors claim that the intervening environmental factors in the corrosion process are considered explicitly in their model.

Even though predictive models are available to predict soil corrosion, these models were found complicated to be used especially when an approximate calculation is required during site investigation. In order to increase the accuracy and reliability of the prediction, most of the models incorporate many parameters in the equation; hence extensive soil sampling and testing to determine the value of those parameters is necessary. Therefore, a simpler approach is suggested to evaluate soil corrosiveness based on potential corrosion growth. Since some of the factors that affect corrosion in soil can be represented by soil resistivity, therefore soil resistivity parameters may be sufficient to indicate the rate of metal loss due to corrosion in soil.

The aim of this paper is to evaluate the influence of soil resistivity towards metal loss of underground steel pipeline through experimental work at five different sites for 12-months period. The five sites were located in eastern part of Peninsular Malaysia. Even though the resistivity is not the only factor that can influence the dynamic of corrosion in soil, yet the experiment will put an effort to determine the correlation between the severity of metal loss and the intensity of soil resistivity measurement using several techniques. The pattern of growth rate will be compared with the pattern of soil resistivity to determine the governance of this parameter upon corrosion growth.

2. Experimental Work

2.1 Steel Coupon Preparation

Direct corrosion testing using buried coupons is the most widely used and the simplest method of underground corrosion testing. Despite of its simplicity, coupons can provide considerable useful information regarding the level of protection of a buried pipeline. The coupons can give a reliable indication of the level of protection, especially with respect to the -850 mV (Cu/CuSO4) polarized potential criterion [17].

A total of 132 steel coupons size 6 cm x 8 cm x 0.7 cm were used in this study. Each coupons were machined from actual pipe segments of grade API 5L X70. The pipes were cut into smaller size as shown in Figure 1. Coatings of those coupons were removed so that the coupons can be tested under worst case scenario [18]. The steel coupons were polished with different degrees of emery papers from the rough to the finest degrees, and then washed with distilled water and degreased with acetone before installed underground. Elemental composition of the X70 pipe is presented in Table 2. The mechanical properties of the coupon at room temperature are as follows: tensile strength of 675 MPa, yield strength of 592 MPa and elongation ration of 26%.

Table 2: Elemental composition of steel coupon grade API 5L X70 in percentage (%).

Carbon	Chromium	Manganese	Phosphorus	Sulphur
0.0784	1.67	0.0123	0.00195	0.00195
Copper	**Nickel**	**Molybdenum**	**Vanadium**	**Aluminum**
0.00871	0.0152	0.00466	0.0114	0.0228

Figure 1: Pipe sampling.

2.2 Coupon Retrieval and Soil Resistivity Measurement

The installation locations were selected according to soil composition and soil resistivity namely Site A, B, C, D and E. Those sites are located along the Eastern Peninsular Malaysia. The total duration of exposure is 12-months and the coupon retrievals were carried out for every 3-months period. The retrieved coupons must not be restored since the coupons has to be taken back to laboratory for cleaning and metal loss weighing, hence disturbing the original condition of the coupons. Therefore, the coupons have been prepared under strict quality control to assure the uniformity of the coupons in terms of dimension and weight. By doing so, time-dependent metal weight loss data which is not recorded from the same sample every time weighing process is done can be used to develop a relationship of corrosion growth over time. All coupons were cleaned according to the requirements of ASTM G1-03 [19]. After cleaning process, coupons were weighed on a precision balance. The mass was subtracted from the original mass of the coupon (before exposure) to calculate the mass loss due to corrosion, and the corresponding corrosion rate can then be calculated.

Soil resistivity was measured using Wenner four-electrode method model M.C Miller soil resistivity test kit which complied with ASTM G57-06 [20]. The measurements are normally made by injecting the earth through two current electrodes (transmitting dipole) and measuring the resulting voltage difference across another two potential electrodes (receiving dipole). From the current (I) and voltage (V) values, an apparent resistivity (R) value is calculated. With regards of modern equipment, the resistance can be measured directly where it automatically switch the transmitting and receiving electrode pairs through a single multi core cable connection. The resistivity, ρ is then calculated as ρ(ohm.cm) = $2\pi aR$ where a is electrode separation (cm), R is resistance (Ω) reading directly from voltmeter. The soil composition, moisture content, and temperature has some impact on soil resistivity. Soil is rarely homogenous and the resistivity of the soil will vary geographically and at different soil depths. Therefore, there is no correction to be made on the electrical resistivity measurements for temperature, which assumed to be constant. Soil resistivity can also be measured in a soil box, and the data can be a useful guide. However the data do not accurately represent in-situ resistivity conditions. Therefore, this study only considered data taken on-site using Wenner four-electrode method.

3. Results and Discussion

Tables 3 and 4 show the corrosion growth rate according to time of exposure and soil resistivity value for all sites. The highest resistivity was recorded from Site A while Site C yields the lowest resistivity throughout the 12-month period. In terms of metal loss subject to corrosion, Site C has experienced the most severe corrosion attack as compared to the lowest value from Site A. Both results comply with the previously mentioned theory on the negative relationship between soil resistivity and corrosion potential. Figure 2 was constructed to graphically examine the relationship between soil resistivity and corrosion rate for all sites. Using bar graph and linear regression method, the average soil resistivity (Average Resistivity) and average corrosion rate (Average C.R) shows contradict line pattern; hence reflect the negative relationship between soil resistivity and corrosion rate. In the other word, as the soil resistivity reduces, corrosion is expected to progress at higher rate.

Table 3: Corrosion data for 3, 6, 9 and 12 months of exposure.

Research area	3-months		6-months		9-months		12-months	
	Mass loss (g/cm^2)	Corrosion rate (mm/y)	Mass loss (g/cm^2)	Corrosion rate (mm/y)	Mass loss (g/cm^2)	Corrosion rate (mm/y)	Mass loss (g/cm^2)	Corrosion rate (mm/y)
Site A	0.030	0.134	0.037	0.104	0.039	0.066	0.045	0.056
Site B	0.047	0.176	0.076	0.187	0.076	0.119	0.129	0.151
Site C	0.031	0.113	0.084	0.204	0.093	0.145	0.188	0.218
Site D	0.029	0.128	0.025	0.068	0.047	0.079	0.047	0.057
Site E	0.028	0.087	0.040	0.089	0.050	0.073	0.065	0.072

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Table 4: Soil resistivity of soil measured in-situ at all sites.

Research area	3-months	6-months	9-months	12-months
	Resistivity (ohm.cm)	Resistivity (ohm.cm)	Resistivity (ohm.cm)	Resistivity (ohm.cm)
Site A	57,805	94,248	81,681	81,681
Site B	459	559	496	503
Site C	92	82	94	104
Site D	4,335	53,721	63,774	25,133
Site E	16,965	13,195	18,221	21,677

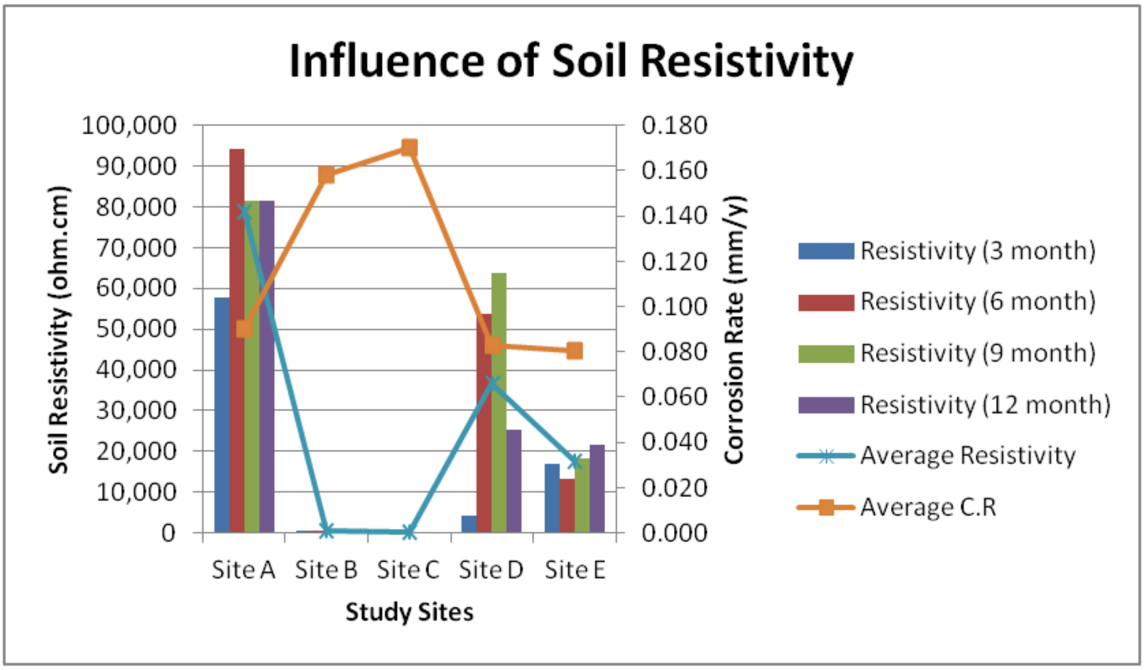

Figure 2: Influence of soil resistivity.

Figure 3 displays the actual relationship between soil resistivity and corrosion rate as a function of time. Based on regression analysis, a negative logarithmic relationship is best to represent the connection of soil resistivity and corrosion growth rate. It is noticeable that high corrosion rate occur at resistivity value less than 20,000ohm.cm. Meanwhile, the corrosion rate shows no significant difference for soil resistivity reading more than 20,000ohm.cm. This expresses that steel buried in soil with resistivity higher than 20,000ohm.cm is unlikely to experience severe corrosion attack.

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Based on the coefficient of determination (R^2), the result of 3-month exposure shows the lowest R^2 value. The R^2 increases drastically after 3-month of exposure and a steady increment was recorded from 6-month of exposure onwards. The highest R^2 value, 0.9612 was recorded at 12-month of exposure time. According to Volk [21], a R^2 value higher than 0.85 is considered reliable for small data set; five samples in this case. This shows soil resistivity alone can be used as a general indicator to roughly determine corrosion rate and soil corrosivity. Figure 4 is constructed using the average soil resistivity and corrosion rate which served as the final reference to estimate soil corrosivity. The high value of R^2, 0.9206 indicates that a reliable estimation can be made based on Figure 4 to predict soil corrosiveness.

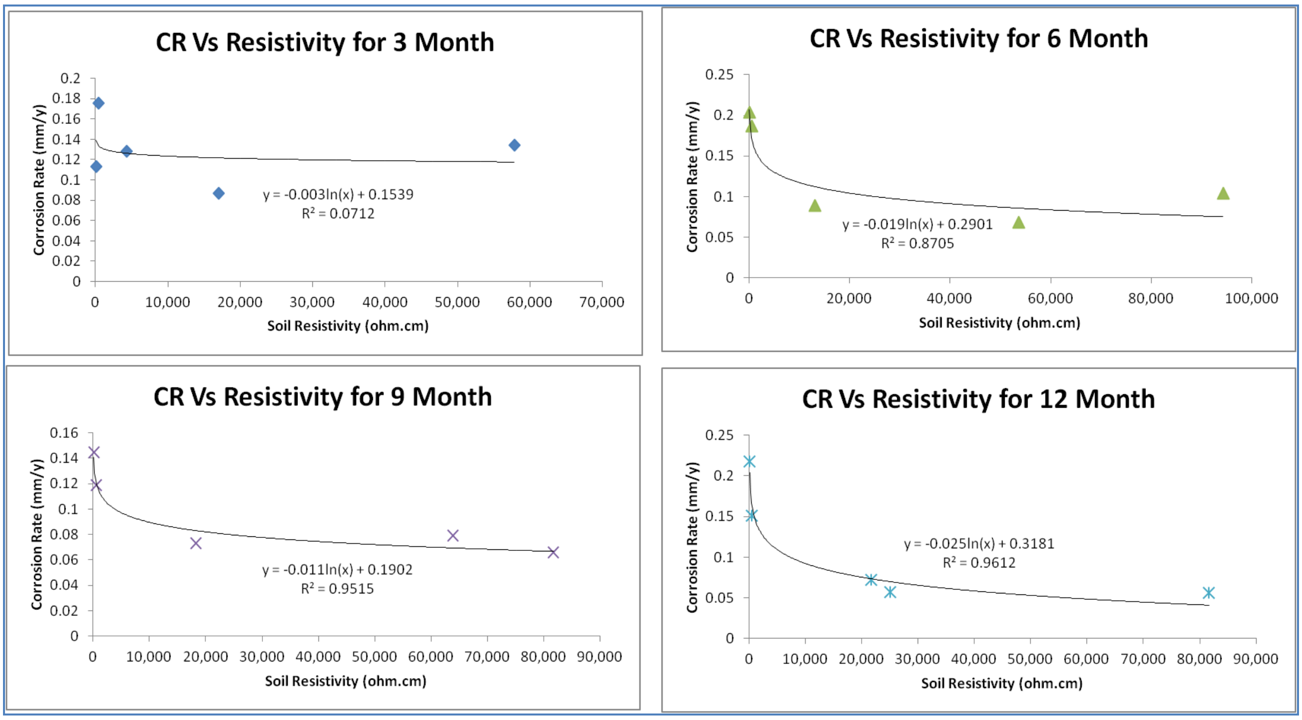

Figure 3: Relationship between corrosion rate and resistivity.

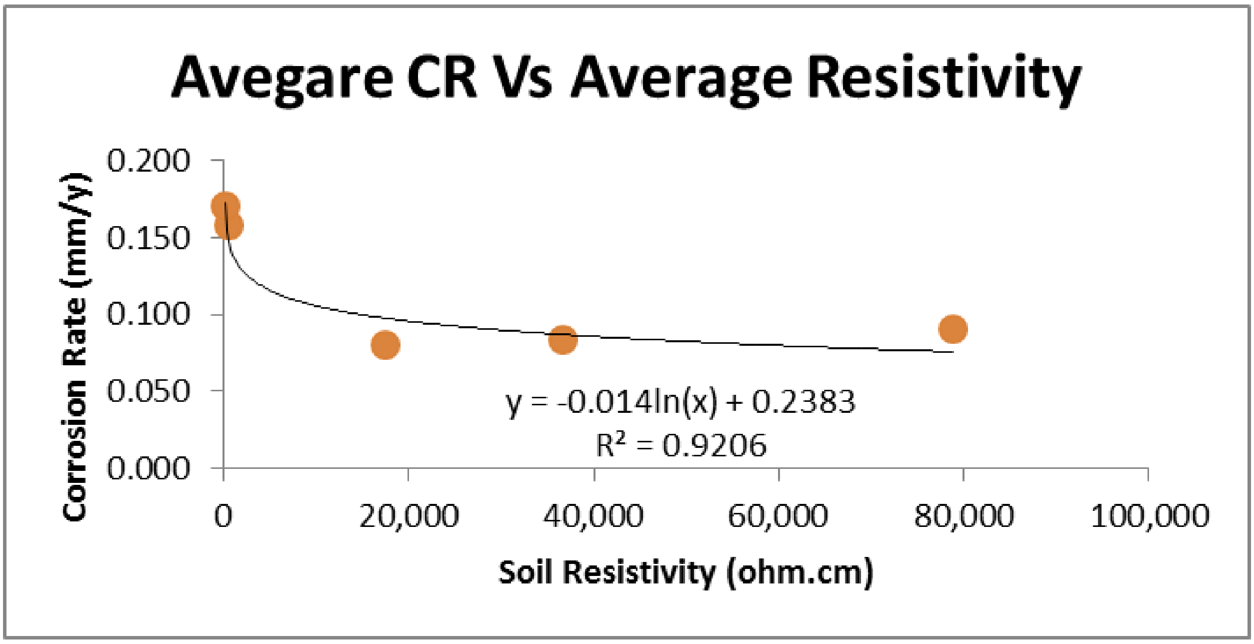

Figure 4: Final reference of soil corrosivity based on soil resistivity.

4. Conclusion

This paper has conducted field corrosion study for a period of 12-months. All buried steel coupons were successfully retrieved and examined for weight loss. The measurement of soil resistivity has been successfully carried out throughout the study. The results show that a negative relationship exists between soil resistivity and corrosion rate. The findings were further affirmed by regression analysis which illustrates a negative logarithmic relationship as the best model to express the relationship between soil resistivity and soil corrosiveness. The results signify the longer the exposure time, the more stable the relationship between soil resistivity and soil corrosiveness. To conclude, soil resistivity alone can serve as general indicator to determine soil corrosivity based on potential metal loss. This may simplify the procedure of assessment during site investigation whereby speedy results can be obtained during site investigation.

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