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Effect of Soil Conductivity on the Design of Cathodic Protection Systems Used in the Prevention of Pipeline Corrosion

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Abstract. One of the most influential factors affecting the rate of corrosion of a buried pipeline and the design of the cathodic protection systems is the conductivity of the soil. The present paper is designed to study the effect of this factor on the design of cathodic protection systems, i.e. the current required to achieve comprehensive protection. Several corrosive environments were studied within the laboratory. The classification of environment corrosivity approved by ASTM was the base of the categorization of these environments. These environments were simulated by adding certain amount of distilled water mixed with weighed amount of sodium chloride to the soil. Several runs were carried out, whereas the conductivity of the soil and the linear polarization curves for the cathode and the anode were obtained during each run. The boundary element method (BEM) was used to compute the total current required using linear polarization curves as the boundary conditions for calculations. The BEASY software based on BEM was used to compute the total current required. The relationship between the total current and the soil conductivity values were drawn. Two equations governing and controlling this relationship were derived.

1. Introduction

Designing and optimization by utilizing computer programs have been applied primarily to cathodic protection systems in the seawater of relatively high uniformity and conductivity. Buried structures have not been modeled readily because of the added complexity of a non-uniform, low conductivity electrolyte. However, modeling would appear to be a likely candidate for future development in impress-current cathodic protection systems in view of the large current and potential field that must be present and the inaccessibility of the protected surfaces in buried structure. As computation methods develop, modeling will probably become further limited by a lack of experimental data to feed the model. Polarization data as a function of time and scale formation have not been determined for most practical environmental conditions (Jones, 1996).

The selection of a suitable current density output is critical for the cathodic protection designers. Indeed, some publications are misleading in that they imply that a fixed current density is sufficient to provide cathodic protection in all circumstances. The current density requirement is extremely dependent on the structure corrosion rate that stated before cathodic protection system is applied. For example, if the surrounding environment of the structure is alkaline, there is little chloride present, the diffusion rate is very low and the structure is not actively corroding, a very low current density is sufficient to prevent any corrosion. At the opposite extreme, areas with minimal cover, a warm, wet, fluctuating environment with high oxygen and chloride levels will have a very high current density requirement (Tomashov, 1996). When a metallic structure is immersed or buried in a conductive medium, the ability of the medium to carry current will influence the magnitude of galvanic currents and cathodic protection currents as well (ASTM G-57, 1995). Soil is a complex, dynamic environment that changes continuously and seasonally, both chemically and physically.

Amaya and Aoki (2005) introduced certain objective function (Eq. 1) describes the relationship between the current density required (in terms of power) and several parameters such as the polarization curves of the electrodes (cathode and anode), the depth of the anode and the cost to lay the anode underground, etc.

$$P\ (i,x) = f\ (i_e) + k_{zo}\ z_e \qquad (1)$$

where:
P = the power in Watt
x = the distance of the anode in meter
i = is the current density in A/m^2
$f\ (i_e)$ = the polarization curves of cathode and anode
k_{zo} = the coefficient to lay the anode underground
z_e = the depth of the electrode

The precise determination of the soil conductivity and its relationship to cathodic protection current will affect the performance and economics of any cathodic protection system. This work is an attempt to establish a relationship between the soil conductivity and the required cathodic protection current.

2. Theoretical background and Experimental Procedure

2.1. Theoretical background

A variety of computational methods have been applied to the analysis of cathodic protection systems. These methods have been used on a wide variety of structures. There are significant advances in modeling applications, but still some areas in which computational modeling approach can be further developed and even improved. More complex models for electrochemical system can be treated with general numerical techniques. The choice of these packages is based on software characteristics (availability, cost and support), hardware requirements, generality, and efficiency. The model provides a powerful technique to obtain the required solutions. Sun and Liu (2000) use Newton-Raphson iterative method for the calculation of current and potential distribution of cathodic protection models with nonlinear polarization curves. Boundary element technique has been found to be suitable for modeling corrosion problems (Yan *et al.*, 1993) as only the surface has to be defined and values of potential and current density are computed with high accuracy on the metal surfaces. These processes give prediction and simulation with high accuracy and reliability (Degiorgi *et al.*, 1999).

The equation governing the current flow and the potential in the electrolyte can be derived from first principles. The continuity equation (charge conservation) requires that the current per unit volume I relate to the charge q by (Jia *et al.*, 2004):

$$-\nabla\ I = (\delta q/\delta t) \qquad (1)$$

For a system in steady state, $(\delta q/\delta t) = 0$. Taking into account the relationship of electric field intensity, E,

$$E = -\nabla\ \Phi \qquad (2)$$

and Ohms law,

$$I = k\ E \qquad (3)$$

where k is the conductivity of the electrolyte. The continuity equation transforms to

$$\nabla\ k\ \nabla\ \Phi = 0 \qquad (4)$$

For an electrolyte with uniform, isotropic conductivity, k is a constant, so that,

$$\nabla^2\ \Phi = 0 \qquad (5)$$

Therefore, for a uniform, isotropic electrolyte, the potential obeys Eq. (5) which is the Laplace equation. The current density, at any point inside the electrolyte (soil) can be evaluated by (Jia *et al.*, 2004).

$$I_{xi} = -k\ (\delta E/\delta xi) \qquad (6)$$

where
I_{xi} is the current density flowing in xi direction
κ = soil conductivity at a point x

The BEM is the most flexible method to solve Laplace equation. This method was the focus of this study. The boundary element method (BEM) reduces Laplace's equation (Eq. 5) for the electrolyte domain to surface equation by the application of Green's Theorem. The structure's surface is discretized into a number of surface elements, and Laplace's equation is transformed to a linear system of Eqs. (1) and (2). BEASY software provides the facility to solve Laplace's equation (Eq. 5) by converting the method