



# Mathematical model for cathodic protection in a steel-saline water system

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## Abstract

The corrosion of steel tubes in sea water was controlled by cathodic protection. The impressed current technique was used. The rate of reaction was evaluated as a function of the temperature, pH and solution velocity. In this technique, the polarization method was used to determine the protection potential and current. The rate of zinc consumption, the protection potential, and the protection current are highly dependent on the variables of the study. The boundary element technique was suitable for modelling corrosion problems. The average percentage of error among the experimental and theoretical data was 1.27%.

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## 1. Introduction

Among the various corrosion control methods available, cathodic protection is commonly adopted to control the corrosion of steel. The cathodic protection system is aimed to shift the potential of steel to the least probable range for corrosion [1]. The first attempts at cathodic protection modelling were made using finite difference approaches, but this technique is limited to

two-dimensional and axisymmetric problems. Recently, the finite element method has been used successfully by some researchers [2]. Unlike other applications of the finite element method, the object of a cathodic protection system is not the structure itself but the environment close to the structure. Therefore, it is required to construct a finite element mesh of the medium between the members of the structure and to extend the mesh along the distance to establish a realistic boundary. The boundary element method requires only the discretization of the anode and cathode surfaces; therefore, the numerical problem may be reduced in size, which permits better resolution and a reduction in computer time compared to other methods, particularly for complex geometries [3]. Cathodic protection involves the application of a direct current (DC) from an anode through the electrolyte to the surface to be protected. This is often thought of as “overcoming” the corrosion currents that

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## Nomenclature

$\delta(\zeta - P)$	Dirac delta function
$\zeta - P$	distance between the load point and the field point
$c_i$	concentration of species $i$
$C_{O_2}$	concentration of oxygen
$D$	diffusivity of dissolved oxygen
$D_i$	diffusion coefficient of species $i$
$E$	electrochemical potential
$E_a$	activation energy
$E_p$	protection potential
$F$	Faraday's constant
$I^*$	fundamental current density
$I_j$	component of the current density vector
$J$	mole flux of oxygen
$k$	rate constant of the reaction
$k_d$	mass transfer coefficient
$k_o$	constant
$N$	number of species
$n$	order of reaction
$P$	load point (source point)
$R$	universal gas constant
$T$	temperature
$u_i$	mobility of species $i$
$z_i$	charge of species $i$
$\zeta$	field point or influence point (receiver point)
$\mu$	sea water viscosity

exist on the structure. Cathodic protection eliminates the potential differences between the anodes and cathodes on the corroding surface. A potential difference is then created between the cathodic protection anode and the structure such that the cathodic protection anode has a more negative potential than any point on the structure surface. Thus, the structure becomes the cathode of a new corrosion cell [4,5]. There are two methods for applying cathodic protection: sacrificial anode (galvanic) and impressed current. Each method depends on a number of economic and technical considerations. For every structure, there is a special cathodic protection system dependent on the environment of the structure [6]. Current distribution in a cathodic protection system is dependent on several factors, the most important of which are the driving potential, anode and cathode geometry, spacing between the anode and cathode and the conductivity of the aqueous environment, which is favourable for a good distribution of current [2,7]. Structures commonly protected are the exterior surfaces of

pipelines, ships' hulls, jetties, foundation piling, steel sheet-piling and offshore platforms. Cathodic protection is also used on the interior surfaces of water-storage tanks and water-circulating systems. However, because an external anode will seldom spread the protection over a distance of more than two or three pipe-diameters, the method is not suitable for the protection of small-bore pipe work. [8]. There have been many laboratory studies on the corrosion of mild steel in saline water, but the application of mathematical models has been limited. This is of particular interest in developing a better scientific understanding of corrosion processes. Therefore, the present work considered the two types of cathodic protection that were studied in our previous work [9,10] with the application of a mathematical model. This model was based on the boundary element method.

## 2. Mathematical model derivation

Corrosion engineers are interested in knowing the current and potential on the metal surfaces after two metals are electrically connected. The main objective was to provide a uniform potential distribution on the metal surface for the minimum possible power input. If the cathodic protection technique is developed with a homogeneous region  $\Omega$  surrounded by a boundary  $\Gamma$  and with electrical conductivity  $k$ , the equation which relates the current with the potential is [11]:

$$I_j = -F \sum_{i=1}^N z_i D_i \frac{\partial c_i}{\partial x_j} - F^2 \sum_{i=1}^N z_i^2 c_i u_i \frac{\partial E}{\partial x_j} \quad (1)$$

Defining the conductivity of the electrolyte [12]:

$$k = F^2 \sum_{i=1}^N z_i^2 c_i u_i \quad (2)$$

Eq. (1) becomes:

$$I_j = -F \sum_{i=1}^N z_i D_i \frac{\partial c_i}{\partial x_j} - k \frac{\partial E}{\partial x_j} \quad (3)$$

The first term of Eq. (3) represents the portion of the current density sustained by the concentration gradient, which is generally neglected in large scale simulations. Eq. (3) is reduced to:

$$I_j = -k \frac{\partial E}{\partial x_j} \quad (4)$$

Conservation of charge requires that:

$$\frac{\partial I_j}{\partial x_j} = \frac{\partial}{\partial x_j} \left( -k \frac{\partial E}{\partial x_j} \right) = 0 \quad (5)$$

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