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Original

Mathematical model for galvanic corrosion of steel–copper couple in petroleum waste water in presence of friendly corrosion inhibitor

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Abstract

Galvanic corrosion of steel–copper couple in saline petroleum wastewater in the absence and presence of curcuma extract as corrosion inhibitor was studied as a function of temperature, velocity, and inhibitor concentration. The electrochemical polarization technique was used to evaluate the corrosion parameters. Corrosion currents densities increase with temperature and velocity, while it decreases with inhibitor concentrations. In this investigation, a theoretical model equation was used to analyze the shape of polarization curves. Microsoft Excel program was used to find the galvanic current and galvanic potential. Theoretical results agreed with experimental one.

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Keywords: Galvanic corrosion; Electrochemical measurements; Numerical solution; Microsoft Excel

1. Introduction

Corrosion is a chemical or electrochemical reaction between a metal and its environment that produce degradation of material. There are several kinds of corrosion such as uniform corrosion, galvanic corrosion, crevice corrosion, pitting, intergranular corrosion, etc. Galvanic corrosion happens when a metal or alloy is electrically coupled to another metal in same the environment. There are many methods of corrosion control such as material selection, coatings, inhibitors, and cathodic protection. Corrosion inhibitor is organic or inorganic component that can be added in small amounts to reduce corrosion problems (Khadom, Yaro, AlTaie, & Kadum, 2009a; Khadom, Musa, Kadhum, Mohamad, & Takriff, 2010; Musa, Khadom, Kadhum, Takriff, & Mohamad, 2012). Recently the using of friendly and the natural materials where the aim of researchers that concentrated on studying the kinetics parameters, such as, activation parameters and adsorption behavior of the corrosion inhibition

process (Yaro, Khadom, & Ibraheem, 2011a; Yaro, Khadom, & Wael, 2013; Yaro, Khadom, & Wael, 2014). Application of mathematical modeling was rarely used. Mathematical modeling is a powerful tool for increasing the availability of electrochemical data for a number of materials and environmental systems for industrial applications that enable chemical and materials engineers to predict corrosion potentials and corrosion rates using equations derived from electrochemical principles (Khadom & Yaro, 2011; Khadom, Yaro, Altaie, & Kadhum, 2009b). The present work was a step in the direction of application a mathematical model for galvanic corrosion – saline water – inhibitor system at different operating conditions.

2. Mathematical model

For activation control and to determine the potential of a system, in which the reduced and oxidized species are not at unit activity, the familiar Nernst equation can be employed (Cifuentes, 1987; Fontana, 1987):

$$E = E^o - \frac{RT}{nF} \ln \frac{a_{red}}{a_{oxid}} \quad (1)$$

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or written as:

$$E = E^o - \frac{2.303RT}{nF} \log \frac{a_{red}}{a_{oxid}} \quad (2)$$

where E is the equilibrium half-cell potential, E^o the standard equilibrium half-cell potential, R is the gas constant (8.314 J/K mol), T is the absolute temperature (K), n is the number of electrons transferred, F the Faraday constant (96,487 coulomb/equiv.), a_{red} and a_{oxid} are activities or (concentrations) of oxidized and reduced species. Hydrogen ion activity is commonly expressed, for convenience, in terms of pH. This is defined as (Uhlig & Revie, 1985):

$$\text{pH} = -\log[H^+] \quad (3)$$

Hence, for the half-cell reaction



$$E_{H_2} = -0.0592\text{pH}$$

Tafel slopes (Tafel constants) are determined from the following equations (Fontana, 1987):

$$\beta_a = \frac{RT}{\alpha n F} \quad (5)$$

$$\beta_c = -\frac{RT}{(1-\alpha)n F} \quad (6)$$

for anode and cathode reaction, respectively, where α is the symmetry coefficient, which describes the shape of the rate controlling energy barrier. The relationship between reaction rate and overvoltage for activation polarization is:

$$\eta^A = \pm\beta \log \frac{i}{i_o} \quad (7)$$

where η^A is overvoltage, β as before, and i is the rate of oxidation or reduction in terms of current density. This equation is called the Tafel equation. The reaction rate is given by the reaction current or current density, so the high field approximation gives (Uhlig & Revie, 1985):

$$i_a = i_{o,a} \exp\left(\frac{E - E_{o,a}}{\beta_a}\right) \quad (8)$$

and

$$|i_c| = i_{o,c} \exp\left(\frac{E - E_{o,c}}{\beta_c}\right) \quad (9)$$

The effect of temperature is to change the value of the exchange current density i_o as follows (Uhlig & Revie, 1985):

$$i_{o,T} = i_{o,298} \exp\left[\frac{E_{act}}{R} \left(\frac{1}{298} - \frac{1}{T}\right)\right] \quad (10)$$

Corrosion current for anodic reaction rate can be obtained as (Uhlig & Revie, 1985):

$$I_a = i_{o,a} A_a \exp\left[\frac{\alpha_a n_a F}{RT} (E_a - E_{e,a})\right] \quad (11)$$

$$i_a = i_{o,a} f_a \exp\left[\frac{\alpha_a n_a F}{RT} (E_a - E_{e,a})\right] \quad (12)$$

and the cathodic one is:

$$I_c = i_{o,c} A_c \exp\left[\frac{\alpha_c n_c F}{RT} (E_c - E_{e,c})\right] \quad (13)$$

$$i_c = i_{o,c} f_c \exp\left[\frac{\alpha_c n_c F}{RT} (E_c - E_{e,c})\right] \quad (14)$$

For the case of diffusion control, the reaction current is given by Fick's law (Liberati, Nogueira, Leonel, & Chateaufneuf, 2014):

$$|I| = z_c F D A \left(\frac{\partial C}{\partial x}\right) \quad (15)$$

or its equivalent

$$|I| = z_c F D A \left(\frac{C_b - C_s}{\delta}\right) \quad (16)$$

The limiting current, i.e. the maximum current under diffusion control is obtained when $C_s = 0$, so

$$|I_L| = z_c F D A \left(\frac{C_b}{\delta}\right) \quad (17)$$

or

$$|I_L| = z_c F D A K C_b \quad (18)$$

where the mass transfer coefficient is defined as

$$K = \frac{D}{\delta} \quad (19)$$

The corrosion current is then

$$I_{corr} = I_L = z_c F D A K C_b \quad (20)$$

z_c is used in Eqs. (15)–(20) because in corrosion processes the cathodic reaction is the one likely to be controlled by diffusion. C_b solubility of oxygen in water. The bulk concentration of oxygen changes with pressure, for barometric pressures other than 101.325 kPa (sea level), the bulk concentration of oxygen can be computed from the following equation (Truesdale, Downing, & Lowden, 1955):

$$C_b = \frac{C_{101.325}(P_T - p)}{(101.325 - p)} \quad (21)$$

where C_b is the bulk concentration of oxygen, $C_{101.325}$ is a saturation value at 101.325 kPa (tested experimentally, Table 1), P_T is total pressure (kPa), p is the vapor pressure of water. The mass transfer coefficient (K) in Eq. (19) varies with the flow or relative speed between metal and the environment, the geometry of the system and the physical properties of the liquid. To calculate the variation of K in dynamic environment, dimensionless group are used such as (Yaro, Al-Jendeel, & Khadom, 2011b):

$$Sh = \frac{Kd}{D} \quad (\text{Sherwood number}) \quad (22)$$

$$Re = \frac{d u \rho}{\mu} \quad (\text{Reynolds number}) \quad (23)$$

$$Sc = \frac{\mu}{D\rho} \quad (\text{Schmidt number}) \quad (24)$$

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