



A mathematical model of crevice corrosion for buried pipeline with disbonded coatings under cathodic protection

Wenhe Wang^{a, b}, Kuiling Shen^a, Jun Yi^a, Qingsheng Wang^{a, b, *}

^a College of Safety Engineering, Chongqing University of Science & Technology, Chongqing, 401331, PR China

^b Department of Fire Protection & Safety and School of Chemical Engineering, Oklahoma State University, Stillwater, OK 74078, USA

ARTICLE INFO

Article history:

Received 13 October 2015

Received in revised form

18 January 2016

Accepted 22 March 2016

Available online 25 March 2016

Keywords:

Pipeline

Crevice corrosion

Cathodic protection

Modeling

Coatings

ABSTRACT

Crevice corrosion occurs in a holiday and disbonded region between coating and pipeline steel. Cathodic protection (CP) is generally recognized as the most effective method for corrosion prevention of pipeline, but its effectiveness may be reduced at defects in a disbonded coating. It is difficult to measure and probe corrosion parameters accurately based on experimental work. Therefore, a mathematical model is necessary to identify the phenomena and mechanisms that contribute to the crevice corrosion process. In this work, a mathematical model was developed to determine the evolution of chemical and electro-chemical transient processes of crevice corrosion in NaCl dilute solution, and the effect of cathodic protection and crevice width on corrosion of 20# steel pipeline with disbonded coatings. Results have demonstrated that the extent of crevice corrosion depends on the crevice geometry and could be influenced by the increase of crevice depth and decrease of its width. The oxygen concentrations drop significantly inside a crevice whether CP is applied or not and whether crevice width decreased or not. The pH values and conductivity of crevice solution increase with the time. The research provides a theoretical foundation for cathodic protection of pipelines and establishes an effective corrosion model which can identify the phenomena and mechanisms of the crevice corrosion process. This work could be used to help mitigate the corrosion failure of pipelines to prevent catastrophic accidents in oil, gas and chemical process industries.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Petroleum products and natural gas have been transported over long distances by buried pipelines since the beginning of the 20th century (Muhlbauser, 2004; Parker and Peattie, 1999). Underground pipeline transportation is considered as the most efficient way of transporting oil and gas because it has a lower cost and is relatively reliable. But there are many factors that affect its safety and reliability, such as mechanical damage, third-party factors, ground movement, and corrosion (Baeckmann et al., 1997; Chen et al., 2009; Gan et al., 1994). In particular, corrosion is a significant problem because of a reduction in pipeline reliability induced by the loss of the pipe wall thickness and an increase in the risk of failure. In order to ensure safe and reliable operation of pipelines,

cathodic protection (CP) is generally recognized as the most effective protection method and is usually applied as a coating for corrosion prevention (Baeckmann et al., 1997; Parker and Peattie, 1999; Roberge, 2012). Nevertheless, its effectiveness may reduce at a holiday, which is a defect in a disbonded coating, such as a hole or crack (Chen et al., 2009; Wang et al., 2014). Crevice corrosion will occur in the holiday and disbonded region. Because the crevice gap is very narrow, the measuring probe or electrode is not accessible to the environment inside the crevice (Yan et al., 2007). It is difficult to demonstrate a proposed mechanism based on experimental work (Song et al., 2005b; Brousseau and Qian, 1994). Moreover, understanding of the CP effectiveness at the crack or crevice is not enough by experiments (Betts and Boulton, 1993; Sharland, 1987). Therefore, a mathematical model is necessary to identify the phenomena and mechanisms that contribute to the crevice corrosion process.

Considerable research have been performed to study crevice corrosion of buried pipelines under disbonded coatings with a holiday by mathematical models (Chin and Sabde, 1999; Kennell and Evitts, 2009; Kennelley et al., 1993; Li et al., 2002; Orazem et al., 1993; Perdomo and Song, 2000; Perdomo et al., 2001; Song,

* Corresponding author. Department of Fire Protection & Safety, Oklahoma State University, Stillwater, OK 74078, USA.

E-mail addresses: whwang@cqust.edu.cn (W. Wang), qingsheng.wang@okstate.edu (Q. Wang).

2012a, 2012b; Song and Sridhar, 2008; Song et al., 2002, 2003; Sharland and Tasker, 1988; Sharland, 1988; Song et al., 2005a). For example, it was found that mathematical modeling can be developed to describe transport processes and chemical and electrochemical reactions in a crevice. Song et al (Song, 2012a, 2012b; Song and Sridhar, 2008; Song et al., 2002). developed a mathematical model to predict the chemistry and corrosion rate in a crevice of variable gap; and a modeling of pipeline crevice corrosion under a disbonded coating with or without cathodic protection was performed. Xu et al (Xu and Cheng, 2014). investigated the effectiveness of CP at corrosion defects on an X100 steel pipeline both experimentally and numerically. A finite element model was developed to simulate distributions of local potential and anode/cathodic current density inside the defect. Results demonstrated that there is a non-uniform potential and current distribution at corrosion defects. To date, the mathematical model of crevice corrosion has focused on the incubation period and development process of crevice corrosion without CP potential, such as a one-dimensional (1-D) model of potential and current density in a crevice with CP potential by Fessler and Schwenk (Fessler et al., 1983; Schwenk, 1983), and a two-dimensional (2-D) model performed by Chin (Chin and Sabde, 1999; Gan et al., 1994). But the theory and model of crevice corrosion with CP potential have not been given more attention because chemistry and electrochemistry parameters in crevices have changed with the times, including crevice width and CP potential (Song, 2008; Sridhar et al., 2001). Moreover, Laplace equations were usually applied to describe the potential and current density distribution model under CP potential in a steady state condition, while effectiveness of time and width on crevice corrosion were not considered (Walton, 1990; Sun et al., 2012; Sun et al., 2013; Sun et al., 2014). Currently, the model of crevice corrosion has only focused on the incubation period and development process in transient state condition without CP potential, but the crevice corrosion process in transient state condition is insufficient in current studies (Sarkar et al., 2012; Xu and Pickering, 1993). Therefore, it is important to develop a mathematical model that can demonstrate the corrosion process, effectiveness of CP, and crevice width for cathodically protected pipelines.

In this work, a mathematical model of crevice corrosion in NaCl dilute solution under a transient state condition was performed based on previous research. The goal is to understand the electrochemical process under CP potential by using the mathematical model. Furthermore, effectiveness of CP potentials (−775 mV, −925 mV and −1075 mV) and crevice width (0.30 mm, 0.45 mm and 0.60 mm) were discussed. The results could be used to determine and prioritize the most effective corrosion preventive strategies and hence mitigate the corrosion failure of pipelines and prevent catastrophic accidents in oil, gas and chemical process industries.

2. Mathematical model

2.1. Model geometry

Crevice corrosion is a complex electrochemical process. The potential and current density of the crevice corrosion process depend on transport of ions species and kinetics of chemical reactions. Chemical and electrochemical parameters in the crevice not only influence each other, but also change with time and space (Betts and Boulton, 1993; Sharland, 1987; Chen et al., 2009; Wang et al., 2014). Generally, some approximate assumptions should be made to simplify and solve the model (Song, 2012a; Song and Sridhar, 2008). A schematic diagram of the model crevice geometry is shown in Fig. 1. The rectangular crevice used in the model of

this work is according to the symmetry of disbondment crevice and uniformity of solution. The crevice forms when a coating disbonds from the pipe's surface and the holiday or the crevice mouth is located at the edge of the disbonded region. Generally, the crevice width ($\delta \leq 1$ mm) is very small and the length-width ratio of the crevice is large (≥ 94). Therefore, the model of crevice corrosion in this work mainly focuses on 1-D simulation along “x”. Ion species transportation controlled by diffusion and electromigration in this model, ion concentration, local potential and current density distribution will be considered on direction “L” along “x”, and the origin point is located in the crevice mouth ($x = 0$). In the model, anodic processes occurred on the internal surface of pipeline steel in the crevice and cathodic processes occurred outside the crevice. Bulk solution diffused from outer surface to inner surface of the crevice, and changed into crevice solution which is different from bulk solution because of the chemical and electrochemical processes (Bagotsky, 2006; Zoski, 2006).

2.2. Model conditions

The bulk solution used in this modeling is a dilute NaCl solution simulating soil ground water, and it is saturated by air. All tests were carried out at room temperature (25 °C) and open to air (Atmospheric pressure is 101.3 kPa). When crevice corrosion occurs in the CP condition, it is assumed that the ion concentration of species in bulk solution is constant because of infinite volume bulk solution outside the crevice (Sharland and Tasker, 1988; Sharland, 1988; Song and Sridhar, 2008; Song, 2012b). Anode dissolution reaction is restrained in the process; when the crevice corrosion is controlled by CP, the crevice solution changed into alkaline solution, so the main reactions in the crevice are oxygen absorption reaction and hydrogen evolution reaction.



Regardless of the ion diffusion and electro-migration that occurred in the process of crevice corrosion under CP condition, the crevice solution is considered as a static state and convection of ions is negligible because of the narrow crevice. Therefore, four species OH^- , Cl^- , Na^+ and O_2 will be considered in the mass transport process. The dilute solution obeys the electric neutrality law of Newman (Sharland, 1988). In this model, the length-width ratio is a large, potential gradient and concentration gradient can be regarded as zero, and only the chemical and electrochemical parameters will be considered along the crevice length direction. Furthermore, the potentials of the pipeline steel are equal and the currents are generated only by ion electromigration.

2.3. General transport equations

In brief, the transport of a given species i is controlled by three mechanisms: diffusion, electro-migration and convection (Sharland, 1988; Song and Sridhar, 2008). The flux of the species in a dilute solution, N_i is given by Eq. (3).

$$N_i = -z_i u_i F C_i \frac{\partial \phi}{\partial x} - D_i \frac{\partial C_i}{\partial x} + v C_i \quad (3)$$

Where N_i represents the flux of species ($\text{mol}/\text{cm}^2 \cdot \text{s}$), u_i is the mobility of species (m/V) given by $u_i = D_i/RT$, Faraday constant $F = 96500$ C/mol, z_i is the charge number, C_i is the concentration of the species, ϕ is the electrostatic potential of system, D_i is the diffusion coefficient and v is the velocity field describing the motion of the electrolyte. In this work, the velocity of the solution is

Download English Version:

<https://daneshyari.com/en/article/586062>

Download Persian Version:

<https://daneshyari.com/article/586062>

[Daneshyari.com](https://daneshyari.com)