Corrosion in underground infrastructures

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There is a significant loss due to corrosion of buried infrastructure. Many pipes have failed due to mistreatment happening within them all around the world. Different soil aeration leads to macro corrosion cells that cause critical levels within the path corrosion leading to a loss of structural integrity of the buried pipes underground. This review paper seeks to address and presents a predetermined model developed by using software COMSOL Multiphysics to identify and characterize the areas experiencing a high rate of corrosion beneath the surface due to differential aeration. The pipe surfaces experience electrochemical reactions and reactant transport mechanisms in the soil and the pipes. Porosity and degree of saturation make the closed-form equations used to create the mass transport properties and electrical properties that constitute three-phase medium using standard soil parameters. The current model enables the study of soil property variations and conditions from the external environment pipeline corrosion. The model results conclude and agree well with the literature and case studies done at pipeline failure sites. The model used in this review will then enable water utilities to develop forecasting tools that may be useful for assessment.

INTRODUCTION

It is challenging to locate and predict the pipes buried underground experiencing corrosion because of lack of access to the assets underground [1-3]. Developing an empirically predictive lifetime equation is challenging, mainly because of the difficulties that occurred in data collection over the lifetime of assets that are accurate and contain the relevant variables to use [4,5]. To prevent these problems, statistical methods were employed previously to factor and assemble the underground corrosion [1-4]. Nonetheless, the effectiveness and the accuracy of the methods rely on field observations and actual valid data [6,7]. Because of the challenges, necessity has been raised to develop a technique to locate and predict the pipelines' overall conditions buried underground [8]. The electrochemical theory can describe the corruptions in soils due to the understanding nature of the approach as an electrolyte and the mechanisms involved [4,9,10]. Past researches and evidence show that soil aerations and the differences

in aeration play an essential role in indenturing the rates of underground corrosion [1,4,5]. Properties of soil such as porosity and saturation are believed to control soil's secondary properties when used as indicators for demining underground corrosion have shown a limited success [3,6]. COMSOL Multiphysics as a model considers the direct and indirect ground aeration results to solve the drawbacks encountered in soil corrosion [11-13]. COMSOL Multiphysics puts together diffusion control mechanisms and the areas active of corrosion and dynamics of product corrosion to determine the long-term effects of underground pollution due to differential aeration [14,15].

Underground corrosion and differential aeration

The formation of macro corrosion couples arises due to a spatial separation of the areas on metal surfaces with different surface potentiality [16,17]. Variations of various soil properties lead to these macro couples within which different aerations can take place [1,4-6]. A shielding effect is created when the formation of insoluble corrosion product occurs [4,8]. The metal is affected thermodynamically, preventing the anodic reaction eventually causing macro cell formation [8,9]. On the other hand, external features inhibit and promote soil aeration and lead to the cells' formation, causing differential aeration [18,19]. An external feature that may lead to that includes the impermeable covers: vegetation, roots, and paving is on the surfaces [20-25]. The waterproof cover formation increases corrosion rate, increasing differential aeration due to the increased ratio of cathode and anode surface area [1,5]. Most of the pipe failures arise due to such localization of corrosion reactions that form corrosion pit [26-30].

COMSOL multiphysics simulation

The model was developed when a 3D model geometry was created to simulate the pipes' sections experiencing blockage of soils with the waterproof cover

covering a more extensive surface exposed to the atmosphere [31-35]. The model was brought to perfection by administering constant concentration boundaries condition to the top surface of one of the half of the block [26,27]. For example, a situation in which pipes are running through a driveway, which prevents the diffusion of oxygen from the lines inside the covered region and promotes differential aeration cells. Iron is the principal constituent of the pipeline alloys, and thus the anodic reaction is the oxidation of iron [36-40].

Most soils have neutral to basic conditions, and thus the cathodic reaction was consider the reduction of oxygen [41-45]

For the underground corrosion, the anodic reaction resulted under control and the cathodic reaction under concentration control.

Soil electrolyte and diffusion of oxygen

The active area of corrosion is the area in contact with the electrolytes because the soil's interface and the corroding metal are heterogeneous [46]. The area of contact is directly proportional to the bulk soil conductivity [47-50]. Different phases exist in the soil structure, which is solid, liquid, and gases [51]. The solids from the structure with capillary porous characteristics, the liquids, and the gases from the pore structure of the soil. The degree of saturation, the level of compactness of the soil, the porosity change the properties of the three-soil structures [52]. The soil electrolyte will reflect the level of corrosivity of the soil [53]. Soil is characterize by its resistivity and conductivity because soil corrosion is associated with the electrolyte of the soil [44]. Soil is characterized as an electrolyte in a model by forming soil solution [54,55]. Furthermore, cathodic control leads to exceeded soil metal corrosions, which proceed in many soils [56]. The limiting oxygen transport caused both cathodic and anodic reactions to the metal surfaces causes the metal in the soil to start corroding [57]. Diffusion is the mode of transport of soil under conditions such as isothermal conditions within the soil structure. The Fick's law modeled diffusion as a mode of transport of oxygen by adjusting diffusion coefficient adjusted to suit the soil factors and elements for the reduction of the area available for diffusion to occur [58-60]. The moisture content and the porosity of the soil affected the rate of diffusion in the soil [61]. Models such as the Millington and the Quirk model occurs in the unsaturated soils and are widely accepted. The perceived diffusion passes only through the air-filled pore in the soil [61-63]. These two models neglect water phase diffusion but on the other hand, accept the air-filled porosity [64]. The diffusion of

oxygen through the water contributes to the corrosion process and at a lower rate and smaller percentage as compared to the diffusion of oxygen through the air [65]. Both phases proposed to cause corrosion and they define the dependence of oxygen transportation properties [66].

Moreover, it is well determined that the soil and the metal to experience corrosion come into contact and as result corrosion starts because of coming into contact with the electrolyte [67,68]. As an anodic reaction of metals, especially iron require an aqueous medium and for that reason, they cause an active reaction in the soil with soil conductivity [68-70]. The full saturation leads to the highest active area whereas the lowest saturation cause low active areas and the surfaces, therefore, resemblance with the original areas [71]. The active area would be important in measuring the corrosion rates in the electrochemical experiments [72,73]. Electrochemical experiments shown that there is a direct proportion between the active area and the electrical conductivity, so they used to measure, and correct the measured corrosion rates [74,75]. When not considering the active surface area, the measured and calculated current density of corrosion was assumed to be disseminated over the whole electrode surface [76,77]. In that way, the overestimation of the current density that measured experimentally to determine the corrosion rate. Modeling the current density attained through experimental work will require the current density to be regulate to suit the active area by using conductivity ratios [78-80]. The modification is therefore included in the anodic terms of density which is currently employed in the corrosion process [81,82].

Time dependent behavior of corrosion products

Concurrently, the corrosion of products is embedded and dependent on the time behavior [83]. The change in mass of species is related to the current densities according to Faraday's law of electrolysis [84,85]. The molar flux of Fe (II) lost by corrosion is converted into a thickness that is defined by the molar mass of species involved and the density of the material [86,87]. A decrease in thickness because of corrosion leads to the loss of iron. Besides, the product corrosion deposition has molded as the increasing thickness of the electrode [88,89]. The current density of the anodic reaction resulted in the loss of the metal and the current density of the cathodic reaction lead to corrosion product deposition [90]. The shielding effect of corrosion products is molded due to the passivation of the metal surfaces because of the reaction of iron hydroxide and the molar mass and density of the metals [83,84]. The surface cover of iron hydroxide corrosion on products [85]. Measures the contribution of active and passive current densities. The sigmoid function has included the effect of passivation currently by the modification of anodic

current density [86,87]. The thickness of the corrosion product on layers formed due to anodic reaction acts as a factor of modifying the passivation [88].

Soil medium characterized by the degree of saturation and the porosity of soil as well as the time-dependent factor [89]. For this reason, COMSOL was used to calculate the electric potential distribution of oxygen concentration and the anodic and cathodic densities which results thereafter on the surface of the transmission pipes [89,90]. Differential aeration resulted in the formation of macro corrosion cell on the pipes backed up by electrode potential and the trends of electrolyte potential [88].

CONCLUSION

Modeling using COMOSOL Multiphysics revealed as a valuable tool to address the underground corrosion influences by differential aeration. Effects of differential aeration and passivation resulting from corrosion products lead to the formation of macro corrosion cells, thus the corrosion of pipes inside with poor access to oxygen. A relationship exists between corrosion mass rates and time-dependent mass loss together with empirical studies. This model has confirmed optimum moisture content for the underground corrosions, mostly studies by many researchers. Finite element models could give valuable insights if they are well combine with experimental shreds of evidence regarding underground pollution.

Acknowledgement

This work was supported by the Technology Agency of the Czech Republic (TAČR) under project No. TK01010040.

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