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Mathematical Modelling of Corrosion for Polymers

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Abstract The material of pipelines transporting water is usually polymers. Chlorine as oxidant agent is added into the water system to prevent the spread of some disease. However, exposure to a chlorinated environment could lead to polymer pipe degradation and crack formation which ultimately reaches a complete failure for the pipes. To save labor, time and operating cost for predicting a failure time for a polymer pipe, we focus on its modeling and simulation. A current kinetic model for the corrosion process of polymers due to the action of chlorine is extensively analyzed from the mathematical point of view. By using the nondimensionalization method, the number of parameters in the original governing equations of the kinetic model has been reduced. Then, the dimensionless set of differential equations is numerically solved by the Runge Kutta method. There are two sets of simulations which are low chlorine concentration and high chlorine concentration, and we captured some essential characteristics for both types. This approach enables us to obtain better predictive capabilities, hence increasing our understanding of the corrosion process.

Keywords Corrosion, Kinetic Model, Mathematical Modelling, Dimensionless

1 Introduction

Corrosion on polymers can be obviously seen when there is crack on the polymer surface. However, the corrosion on the polymer is often hard to discover where the material looked normal but internally the strength of the material is weak. In physical testing, it is hard to determine the state of the material and to decide when the maintenance need to take place. To make things worse, sometimes after an accident occurred, then we realized that there is corrosion. To save labor and time, and for the safety purpose, simulation of the corrosion process is necessary to test various conditions and determine the failure time of the pipe. Colin [1] presented a satisfactory prediction of molecular weight loss during the corrosion process. Here in this paper, his kinetic model is extensively studied to analyze the oxidant and antioxidant concentration profiles in polymer pipes.

Deterioration of polymer is one of the main concerns for people working with pipelines industry. A significant effort has been devoted to studying the corrosion due to environmental conditions. Compared with pipes made from other material, the polymer is an anti-corrosion material and low cost compared to metal. Even the polymer is an anti-corrosion material, the exposure to oxidant agent, high pressure and temperature affect the performance of the polymer. The process of polymer corrosion consists of chemical reaction, diffusion, and mechanical deformation. The chronology of corrosion of polymer pipes due to chemical aging is as follows [3]: (a) A polymer is exposed to chlorine (oxidant agent/disinfectants). (b) The antioxidant is added to prevent corrosion. (c) Antioxidant react to the oxidant agent. (d) Antioxidant disappeared slowly (migration). (e) Oxidant absorbs on the polymer surface. (f) Polymer reacts to oxidant directly causing to chain scission and make the molecular chain shorter. Hence, the cause of polymer corrosion is radical chain-oxidation [5].

Polymer pipes that transporting water will undergo failure after a certain time due to the physical and chemical aging. The water contains two reactive species which are oxygen and disinfectants (chlorine dioxide). Disinfectants will destroy organic compounds, often by radical processes. It degraded the inner surface of plastics pipelines, developed cracked and eventually reach a complete failure. The lifetime of a pipeline is normally 50-100 years, however, these factors make the degradation goes faster so that the lifetime becomes shorter i.e. 1-25 years [3].

The complexity of corrosion processes creates the necessity for a quantitative model approach to developing predictive tools, which simultaneously provide both quantitative information as well as simulations of the various processes involved.

The kinetic equations of polymer corrosion have been extensively studied and many kinetic models have been proposed [1][2]. The mechanisms of polymer degradation induced by chlorine dioxide in terms of the kinetic model have been established by [1]. Ge et al. [3] developed a model to investigate the time-dependent crack propagation in a viscoplastic polymer. Their result shows that failure behavior is dependent on the applied load.

The objective of this research is to analyze the oxidant and antioxidant concentration profile in polymer pipes. By analyzing these components, the primary aging process of the pipes