Development of Prediction Model for Pipe Wall-Thinning by Flow Accelerated Corrosion (FAC)

Background

Management of pipe wall-thinning, especially Flow Accelerated Corrosion (FAC)*1 of carbon steel, is a very important subject in coolant systems of power plants. Construction of a prediction equation for pipe wall-thinning by FAC based on mechanistic model is desired for the rational management in addition to the wall thickness measurements. Because, the thinning tendencies in an area with a difficult wall thickness measurement or an area with little frequency of inspection can be evaluated by the equation. Moreover, the effect of modification of the operating condition on the lifetime of piping, such as improvement of water chemistry and power uprate, can be evaluated. The major influence factors of FAC, such as material, flow condition, temperature, and water chemistry, should be included in the mechanistic model and the prediction equation.

Objectives

The purpose of this study is to construct the FAC model and the prediction equation of wall-thinning including the major effective factors;

Principal Results

1. Effect of hydraulic factors (mass transfer coefficient) on FAC

As an evaluation method of mass transfer coefficient, the essential hydraulic factor affecting FAC, which can be applied to strong eccentric turbulent flow condition with high FAC susceptibility, a new mass transfer model was built by considering the increase of both averaged and fluctuation velocity at near-wall region (Fig. 1). The model was applied to experimental data of FAC test, and the validity of the consideration of fluctuation velocity (turbulent velocity *2) in the model was confirmed (Fig. 2).

2. Effect of water chemistry and material factors on FAC

The FAC model focused on the water chemistry and material was constructed by assuming the following processes (Fig. 3). 1) The saturated layer of iron and the diffusion layer are formatted on the surface of material. The rate-determining step of FAC is the diffusion of the soluble iron species between bulk solution and saturated layer through the diffusion layer. 2) The stability of surface oxide is influenced by the chemical condition in the saturated layer, which is determined by the diffusion of oxygen from bulk solution and consumption of oxygen by corrosion.

The thermodynamic solubility of iron, the major water chemical factor of FAC, was evaluated based on the model (Fig. 4). The effect of dissolved oxygen concentration was also taken into consideration in the model. The model reproduces the experimental results *3, which indicate the drastic decrease of FAC rate by the increase in dissolved oxygen concentration (Fig. 5).

3. Development of prediction equation for pipe wall-thinning by FAC

The prediction equation for pipe wall-thinning was constructed based on the above FAC model. The calculated results by the equation reproduce the well-known temperature dependence of FAC and indicate the temperature peak of FAC rate at 140℃ (Fig. 6).

Future Developments

The evaluation of the oxide film thickness will be included in the model. The validity of the present model will be confirmed by using some experimental results and the wall-thinning rate of piping at actual power plants.

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Reference

K. Fujiwara, et al., 2009, "Effects of water chemistry and fluid dynamics on wall thinning behavior (part 1)", CRIEPI Report Q08016 (in Japanese)

K. Yoneda, et al., 2008, "Quantitative evaluation of effective factors on flow accelerated corrosion (part 2)", CRIEPI Report L07015 (in Japanese)

*1：One of the wall-thinning phenomenon of carbon steel and low alloy steel piping. FAC was caused by the dissolution of surface oxide film accelerated by the turbulence of flow.

*2：Time averaged value of absolute difference between instantaneous local velocity and local mean velocity

*3：Results of a joint research project conducted by the Japan Atomic Power, Inc., University of New Brunswick (Canadian), and CRIEPI.

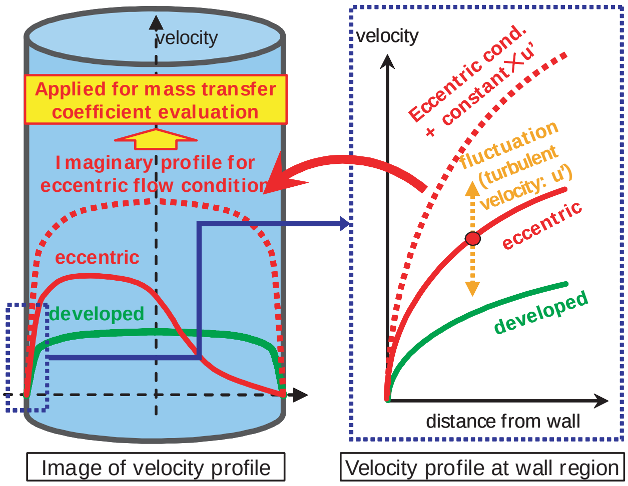

Fig.1 Concept of mass transfer model in eccentric flow

Increase of mean and turbulent velocity at near-wall region in eccentric flow was considered and combined, and an imaginary velocity profile was applied to the mass tranfer coefficient evaluation.

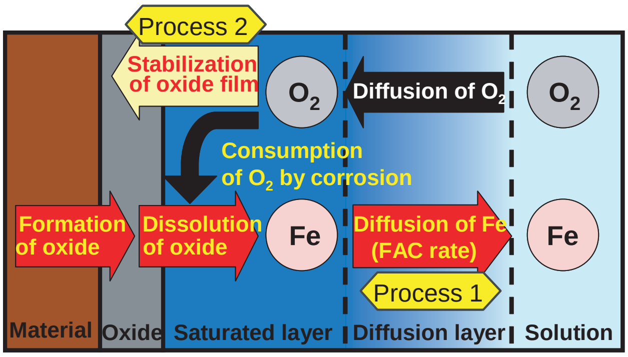

Fig.3 Schematic of FAC model

FAC model under steady-state condition was developed by considering the diffusion and consumption of oxygen in addition to the the dissolusion and diffusion of Fe.

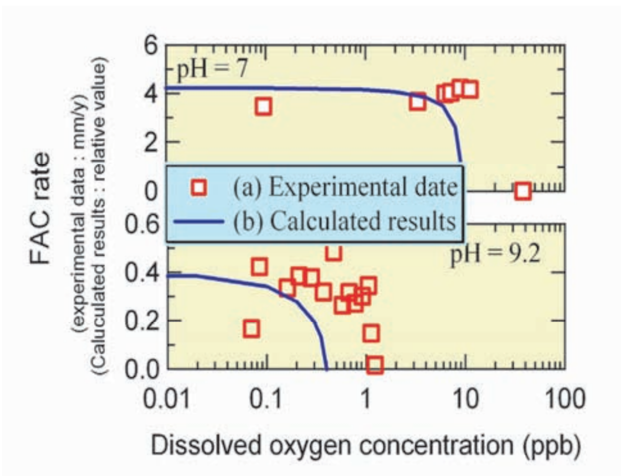

Fig.5 Effect of dissolved oxygen on the FAC rate

The present FAC model reproduces the drastic decrease of FAC rate by the increase in dissolved oxygen concentration under neutral and weak alkaline conditions.

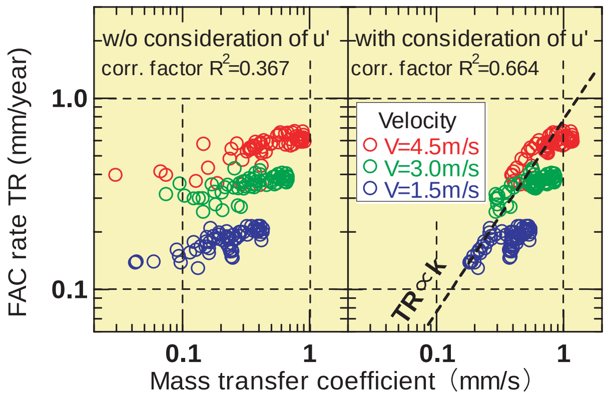

Fig.2 Correlation of FAC rate and mass transfer coefficient

By considering the turbulent velocity (u') in the FAC experiment condition, the correlation of FAC rate and mass transfer showed good improvement, and consequently, qualitative validity of the mass transfer model was confirmed.

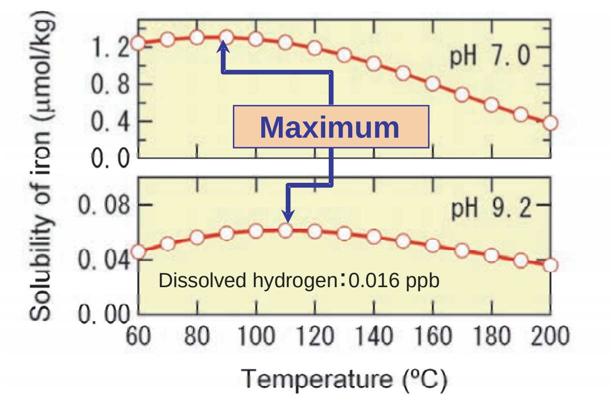

Fig.4 Effect of temperature on the solubility of iron

The maximum of solubility appears at around 100℃. The value in a neutral solution (pH = 7.0) is about 20 times higher than in weak alkaline solution (pH = 9.2).

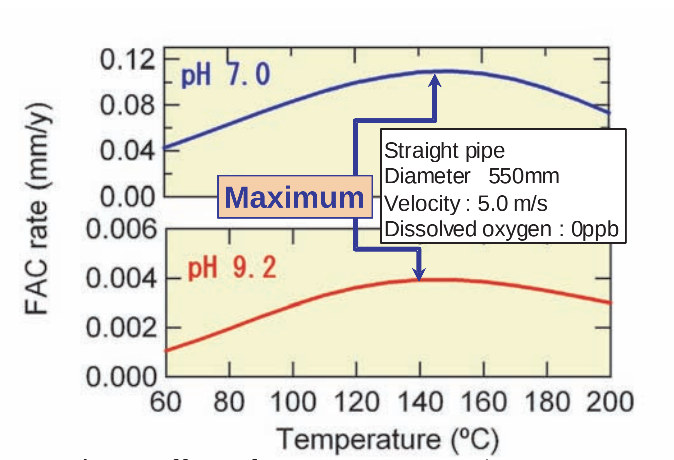

Fig.6 Effect of temperature on the FAC rate

The calculated results indicate the temperature peak of FAC rate at 140℃. The prediction equation qualitatively reproduces the well-known behavior of FAC.