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Evaluation of the Geometric Impact on FAC in Elbow Pipe using CFD and Experiment

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1. Introduction

In nuclear power plants, the circulation piping often expeiences phenomena where the flow velocity accelerates due to changes in pipe diameter or the changes in flow direction, resulting in significant difference in distribution of flow velocity. This can lead to flow-accelerated corrosion(FAC). FAC occurs in the circulation piping due to the occurrence of a metal ion concentration gradient on the metal surface, resulting in reduced pipe wall thickness and it could lead to incidents like pipe rupture. To prevent such occurrences, various countries around the world have assessed multiple factors influecing pipe thinning through computational fluid dynamics(CFD) and pilot test facilities aimed at studing pipe thinning. The analysis of thinning due to FAC through numerical simulations has the advantage of analyzing flow conditions that are difficalut to apply in the experiments based on the data mearsured in demonstration facility. These analysis results can be utilized as preliminary predictive data for tests or reference materials for the managemnet of pipe.

In this study, the flow characterisitcs in a specific pipe shape including orifice and elbow, were idenfigied using computational analysis. From the analyzed resluts, the wall shear stress affeced by geometric impacts was calculated, and the mass transger coefficient was evaluated the thinning rate due to FAC in the pipe. The CFD analysis results of pipe wall thinning were compared with emprical experimental data to assess the impact of pipe geometry.

2. Methods and Results

2.1 Layout for FAC test and CFD analysis

Using an FAC demonstration facility capable of simulating the wall thinning phenomenon in secondary system piping of nuclear power plants, an evaluation of FAC was conducted under temperature and pressure conditions of 150℃ and 10 atm, respectively, with a flow velocity of 5 m/sec. The test was carried out under water chemistry conditions with dissolved oxygen(DO) levels below 5 ppb, conductivity below 1 μS/cm, and pH at around 8 during the experiment.

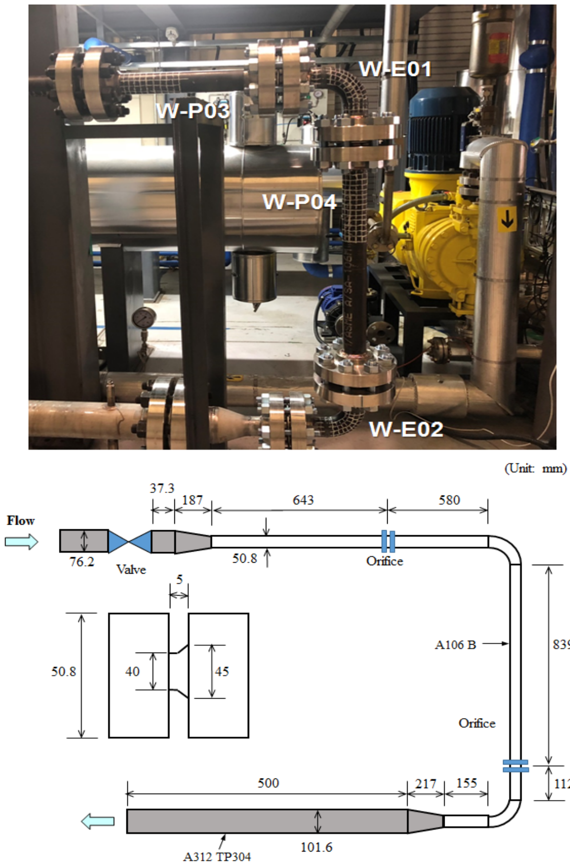

Fig. 1. FAC test pipeline layout.

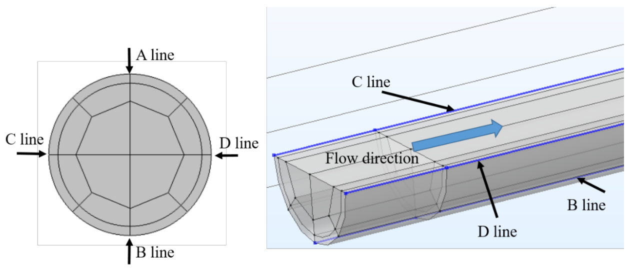

Fig. 2. Pipe locations in mesh settings.

The test piping used was a 2 inch carbon steel pipe (SA 106 Gr.B, Cr 0.04%). Two elbows were installed apart from orifice in distace of 580 mm (W-E01) and 112 mm (W-E02) as shown in Fig. 1. The inside diameter of the orifices is 40 mm, and the ratio to the diameter of the pipe(β) is 0.8. The material of elbow is also carbon steel with a radius of curvature of 76 mm.

2.2 FACtest and simulation results

Flow analysis of wall thinning rates were conducted using COMSOL Multiphsics, which is capable of solving multi-physics problems based on finite elements. The flow characteristics that occur as the fluid moves through the piping and the resulting wall shear stress were determined. These values were then applied to equation (1) through (3) to estimate the FAC rate and mass transfer coefficient at the pipe wall [1-2].

$$\text{FAC rate} = 0.23\tau_{\text{w,RMS}}^{0.40} \quad \text{(1)}$$

$$k_e = \frac{\tau_{\text{w}}}{\rho U_{\text{ave}}} Sc^{-2/3} \quad \text{(2)}$$

$$Sc = \nu / D_{\text{Fe}} \quad \text{(3)}$$

where,
τ_w : instantaneous wall shear stress, RMS: root mean square, ρ : density, Uave : mean cross-section velocity, Sc : schmit number
ν: kinematic viscosity of water, D_{Fe} : mass diffusion coefficient of Fe.

Fig. 3 shows the distribution of flow velocity and calculation results of FAC rate at the first elbow(W-E01). In view of flow directions, there are no points where the flow reverses direction. However, from the starting point of the vertical pipe, the fluid flow moves from the intrados wall towards the extrados wall and, after a certain distance, flows parallel to the pipe again. The FAC rate calculated uisng the mass transfer coefficient showed the maximum value(~0.8 mm/yr) at the intrados surface.

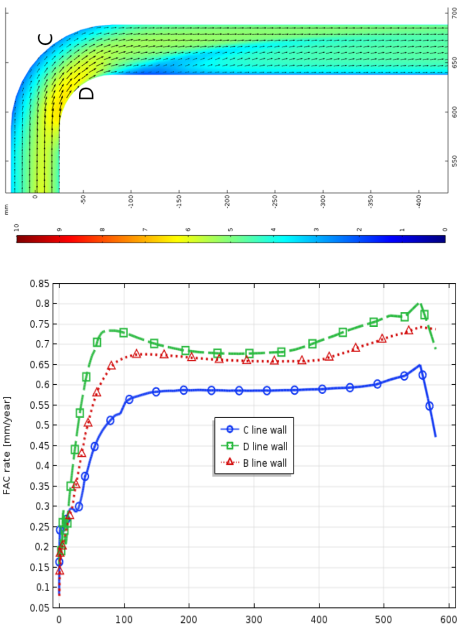

Fig. 3. CFD analysis results of flow velosity distribution and FAC rate on W-E01.

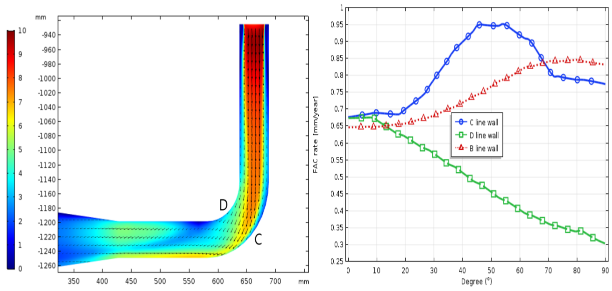

Fig. 4. CFD analysis results of flow velosity distribution and FAC rate on W-E02.

Fig. 4 shows the velocity distribution and FAC rate for the second elbow(W-E02) section. Due to its closer distance to the orifice compared to the first elbow, it exhibits a higher flow velocity distribution. Unlike the first elbow, the FAC rate is higher on the extrados surface (maximum value of ~0.95 mm/yr).

Comparing the FAC rate(~0.38 mm/yr) of the straight pipe measured in the experiment, The geometric factors of W-E01 and W-E02 are 2.1 and 2.5 respectively.

3. Conclusions

Pipe wall thinning tests simulating operations in nuclear power plants were conducted on carbon steel piping connected by orifices and elbows. A 3-dimensional fluid analysis was performed to calculate the flow distribution and pipe thinning rate. The results of analyzing the flow velocity, pressure, and thinning rate at each position of the test piping layout generally showed that the FAC was closely related to flow velocity and geometric impact such as distance from orifice.

ACKNOWLEDGMENTS

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