Numerical Study on Flow Accelerated Corrosion in Different Pipe Components

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1. Introduction

Flow accelerated corrosion(FAC) is one of well-known causes of wall thinning of piping components in nuclear power plants[1]. When the thickness of piping components reduces to less than the critical thickness, a ductile failure of the components occurs. High temperature steam or water could spurt from the failure components by suddenly rupture on the degraded components. Therefore, prediction of the wall thinning on the piping components is very important in nuclear power plants[2]. In this study, we have been analyzed the FAC rate by calculating the mass transfer coefficient on the primarily piping components.

2. Evaluation Methodology of the Flow Accelerated Corrosion rate

2.1 Flow Accelerated Corrosion(FAC)

The Rate of FAC depends on three groups of parameters, such as water chemistry, flow and materials. While water chemistry and materials set an overall propensity for FAC, local flow characteristics determine the local distribution of wall thinning. For FAC cases where flow effects are dominant, the FAC rate is proportional to the mass flux of ferrous ions. And the mass flux of ferrous ions is a function of the mass transfer coefficient(MTC).

2.2 Mass Transfer Coefficient(MTC)

FAC rate(mass flux of ferrous ions) is calculated from MTC and the concentration difference of ferrous ions(C_w - C_b). However, concentration distribution inside the oxide layer is not predictable. But, if the piping is short enough and the concentration of ferrous ions at the wall is assumed properly, the concentration difference becomes a constant. And also the constant allows a conversion of MTC into FAC rate. Therefore, qualitative assessment of the FAC rate is possible through the MTC Analysis.

The mass transfer coefficient k_c can be expressed as Eq.1 based on the Chilton-Colburn equation[3, 4].

$$k_c = (\tau/\rho u)S_c \qquad \text{Eq.1}$$

where: k_c mass transfer coefficient; τ wall shear stress; ρ fluid density; u wall adjacent velocity; S_c Schmidt number.

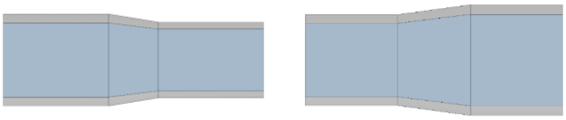
3. Numerical Analysis Method

For the numerical analysis, we selected five type of pipe components, such as straight, 90° elbow, reducer, expander and tee straight pipes(Shown in Fig. 1). Geometry models which is nominal pipe size(NPS) 2.5 and schedule number 80 pipe size was basically used for all piping components. The pipe outer diameters at the downstream were determined as NPS 2 pipe in case of the reducer and NPS 3 in case of the expander. In case of the 90° elbow, radius of curvature was determined at 1.5 times of the pipe diameter. To set similar flow length of fluid through the piping components, length of each components was defined based on the arc length of center line in the 90° elbow case. In the tee straight pipe, fluid inflows through one inlet (upper part) and comes out through two outlets (side parts).

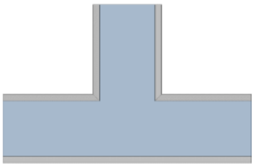
The evaluation region of the FAC consists of each piping components and straight pipe, which length was defined at 1.5 times of the pipe diameter, at the upstream and downstream. Additionally, straight pipe, which pipe length was defined at 15 times the pipe diameter in order to obtain a fully developed flow in the evaluation region and prevent the back flow at the downstream region.

The upstream flow conditions were determined based on the flow condition of CANDU 2.5inch feeder pipe[5]. The working fluid is water at a constant temperature 310℃, and the reference pressure is equal to 10 MPa. Mass flow rate is 26 kg/s. Reynolds number about $6.83\text{x}10^6$ in inner region of pipe were used as the

(a) Straight (b) 90° Elbow



(c) Reducer (d) Expander



(e) Tee Straight

Fig.1 Configuration of the piping components upstream flow conditions. Carbon steel(A106) was assumed for the piping components, and roughness of 0.075mm was applied on inner surface of wall.

In this study, 3D steady CFD(computational fluid dynamics) analysis has been conducted with incompressible fluid flow. To calculate the flow field, continuity equation(Eq.2) and momentum equation(Eq.3) have been used. And K-ε turbulence model is also adopted to consider turbulent effect.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0 \qquad \text{Eq.2}$$

$$\frac{\partial}{\partial t}(\rho \vec{V}) + \nabla \cdot (\rho \vec{V}\vec{V}) = -\nabla p + \nabla \cdot (\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F} \qquad \text{Eq.3}$$

The MTC was calculated based on the wall shear stress and the wall adjacent velocity through an evaluated value from CFD analysis. This evaluation methodology has been performed through a user-defined-function(UDF). The wall shear stress, turbulence intensity and velocity at the wall adjacent cells have been evaluated with MTC in this study.

For the all cases, grid systems have been generated to have substantially the similar Y+ value at the first cell from wall. Furthermore, dense grid systems have been used on the adjacent region of the wall, because of Y+ value at the wall adjacent cell affect to the accuracy of the analysis result. About 500,000 grids are used in the entire calculation domain for the CFD analysis, depending on shape differences.

4. Analysis Results

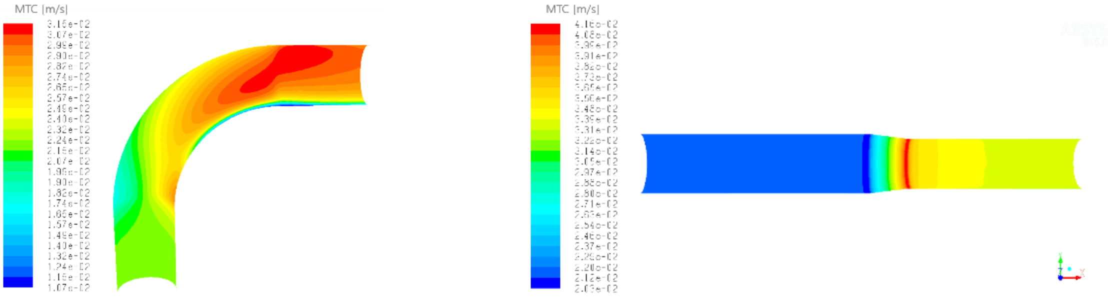
The fig.2 showed the MTC distributions at the inner wall of the four piping components. The fig.1(a) showed that the higher values were on the intrados at the start of the bend and extrados at the end of the bend and the lower values were on the extrados at the start of the bend and intrados at the start of the bend. This results were consistent with previously published experimental study[5].

Graphs of MTC, wall shear stress, turbulence intensity and wall adjacent velocity at the inner wall of piping components are shown in Fig. 3. In this figure, all evaluation parameters of FAC rate showed similar tendency. At the inner wall adjacent region, the maximum MTC increased by 10%, 40%, 90%, and 150% in the expander, elbow, reducer, tee straight piping components, respectively, compared to the straight pipe (Fig. 3(a)). The tee straight showed much higher value than other cases.

5. Conclusions

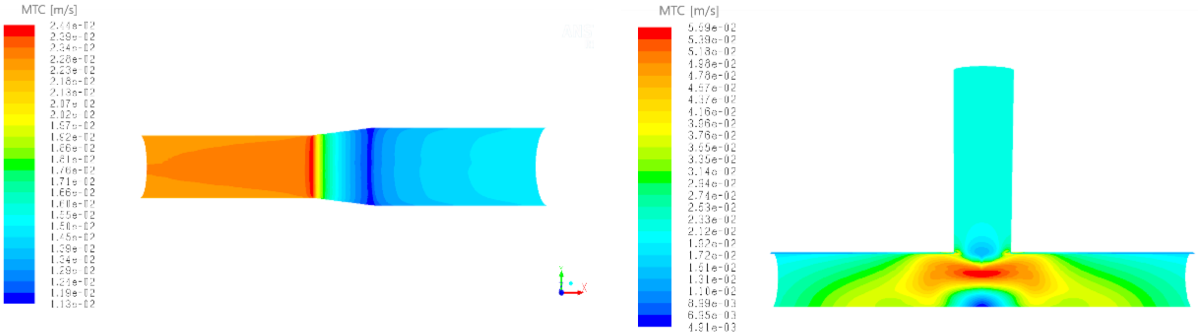
In this study, numerical analysis has been performed to evaluating of the FAC rate in different pipe components. For the numerical simulation, five type of piping components were considered. And FAC rate has been evaluated based on the MTC, wall shear stress, turbulence intensity, and wall adjacent velocity.

The results of this study showed that evaluation



(a) 90° Elbow

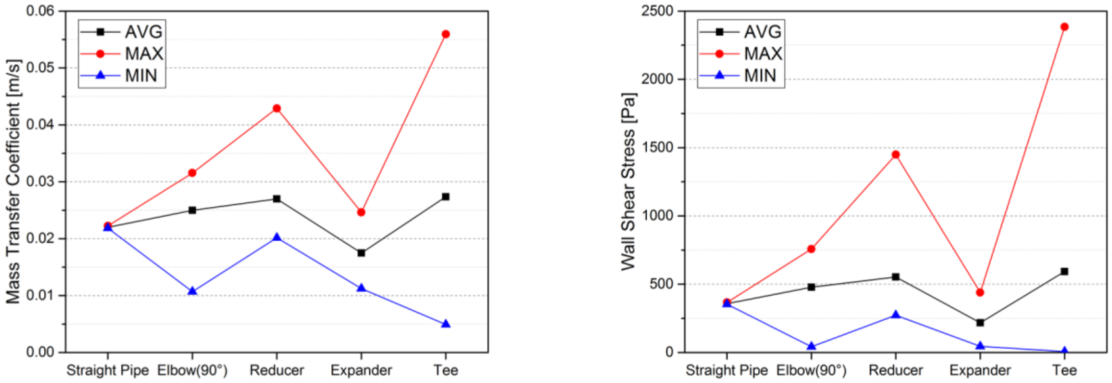
(b) Reducer



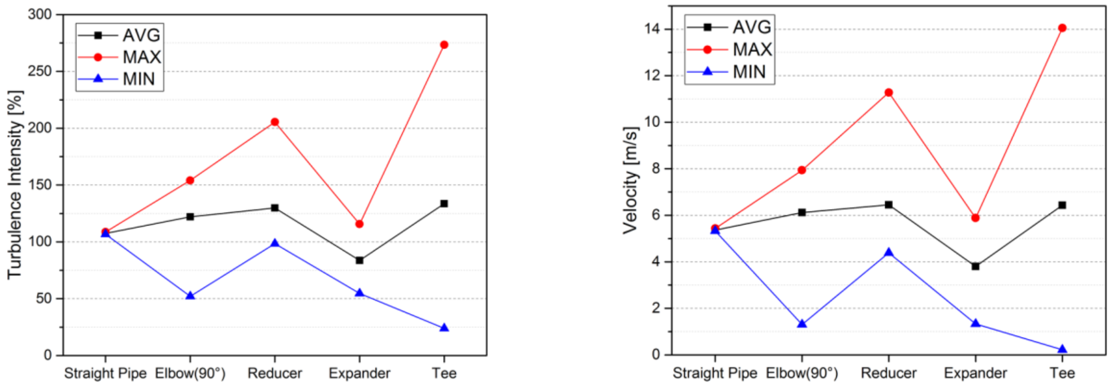
(c) Expander

(d) Tee straight

Fig.2 MTC distributions at the inner wall of the four piping components



(a) Mass Transfer Coefficient (b) Wall Shear Stress



(c) Turbulence Intensity (d) Wall Adjacent Velocity

Fig.3 Results of parameters to evaluating of the FAC rate

parameters of FAC rate suddenly increased in case of tee straight, compared to the other piping components. Because of the local weak region of piping components may lead to wall thinning by FAC. Effect of shape difference should be considered according to type of piping components, when the evaluate the FAC rate. The results of this study may be useful for developing evaluation methodology of FAC rate.

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