NURETH14-430

EVALUATION METHOD FOR PIPE WALL THINNING DUE TO LIQUID DROPLET IMPINGEMENT - (II) COMPARISON OF CALCULATIONS WITH MEASUREMENTS AT ACTUAL NUCLEAR POWER PLANTS

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Abstract

The validations on DRAWTHREE-LDI are made through the comparisons of results calculated with those measured in feedwater heater vent lines at an actual power plant. In DRAWTHREE-LDI, pipe wall thinning rates are evaluated by the procedure composed of six steps. Comparison of calculated results by DRAWTHREE-LDI is made with those measured in feedwater heater vent lines at an actual power plant. Most calculated results agreed with those measured within a factor of two which is the target in the development of DRAWTHREE-LDI.

Introduction

Pipe wall thinning is one of the concerns for fossil and nuclear power plants to improve their capacity factors and extend their lifetimes. Liquid droplet impingement (LDI) and flow accelerated corrosion (FAC) are major mechanisms which cause pipe wall thinning. In order to identify components where pipe wall thinning is likely to occur and to investigate countermeasures against pipe wall thinning at actual power plants, analysis code systems, DRAWTHREE-FAC and DRAWTHREE-LDI, have been developed and validated through the comparison of calculated results with those measured at actual power plants [1-5].

In DRAWTHREE-LDI, the analysis code system to evaluate pipe wall thinning due to LDI, pipe wall thinning rates are evaluated by the procedure composed of six steps which are described in detail in Ref. [5]. Pipe wall thinning due to LDI is classified into to two types, i.e., LDI (erosion) and LDI (corrosion):the mechanism of the former is physical erosion due to droplet collisions onto base materials, while that of the latter is chemical reactions which are similar to those cause FAC.

In this article, the validations on DRAWTHREE-LDI are made through the comparisons of results calculated with those measured in feedwater heater vent lines at an actual power plant.

1. Evaluation method on LDI (erosion) and LDI (corrosion)

Since the procedure implemented in DRAWTHREE-LDI is described in detail in Ref. [5] and overviewed in Ref. [6], it is summarized briefly in this section.

Wall thinning rates due to LDI are shown schematically in Fig. 1 as a function of droplet velocity impinging onto materials. In the region with low droplet velocities, the dominant mechanism for wall thinning is LDI (corrosion). As droplet velocities rise, wall thinning rates due to LDI (erosion) increase. In the region with high droplet velocities, LDI (erosion) becomes to be dominant.

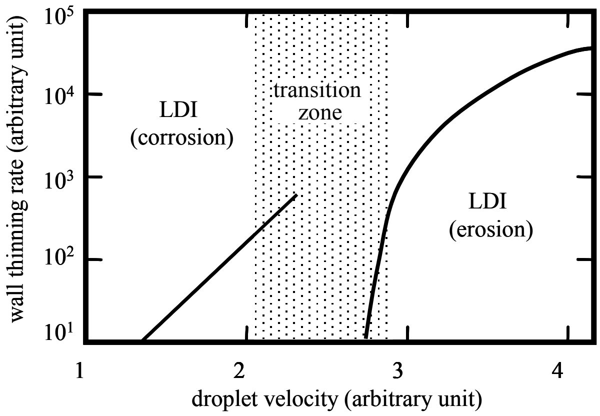

Figure 1 Schematic wall thinning rate due to LDI (corrosion) and LDI (erosion).

The wall thinning rate due to LDI (erosion) is evaluated by the empirical formula proposed by Heymann [7] which is shown in Eq. (1).

$$\log(Re\ ) = 4.8\log(V_r) - \log(NER) - 16.65 + 0.67\ \log(d_p) + 0.57J - 0.22K, \quad (1)$$

where the notations are as follows: Re: rationalized erosion rate (m^3-eroded materials/m^3-collided droplet), NER: erosion resistance number , d_p: droplet diameter (m), J: constant (-) (0 for liquid droplet impingement), and K: constant of geometry (-) (0 for plane surface, 1 for curvature). It is confirmed that the empirical formula proposed by Heymann is the most suitable to evaluate pressure generated on material surfaces due to droplet impingements [8-10].

Figure 2 shows wall thinning rate calculated by Eq. (1) as a function of droplet collision velocity with a parameter of mist weight concentration.

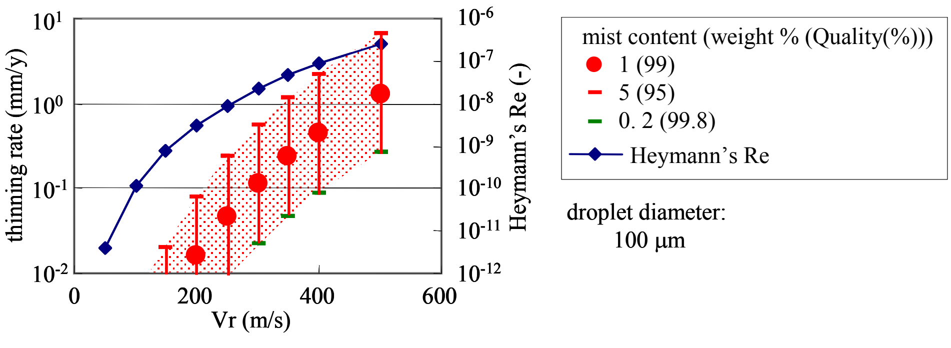

Figure 2 Wall thinning rate due to LDI (erosion).

Wall thinning rates due to LDI (corrosion) are shown in Fig. 3 as a function of mass transfer coefficient which is calculated by means of flow dynamics analysis. Wall thinning rates reduce as the value of pH rises through oxygen concentration in water is small.

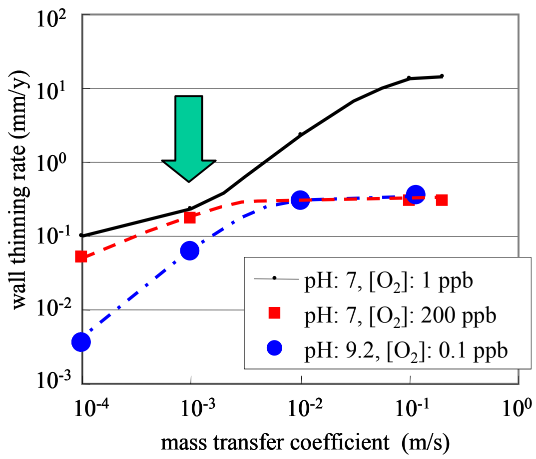

Figure 3 Wall thinning rate due to LDI (corrosion).

2. Wall thinning calculation by means of DRAWTHREE-LDI

The wall thinning measurements were made in the feedwater heater vent lines at an actual power plant. Figure 4 shows a diagram of the feedwater heater vent lines. The bends where the measurements were made are marked by the circles in Fig. 4. All the lines connect from the feedwater heaters to the condenser. The orifice is installed in each line at a position close to the connection to the feedwater heater. Major parameters of the feedwater heater vent lines are summarized in Table. 1.

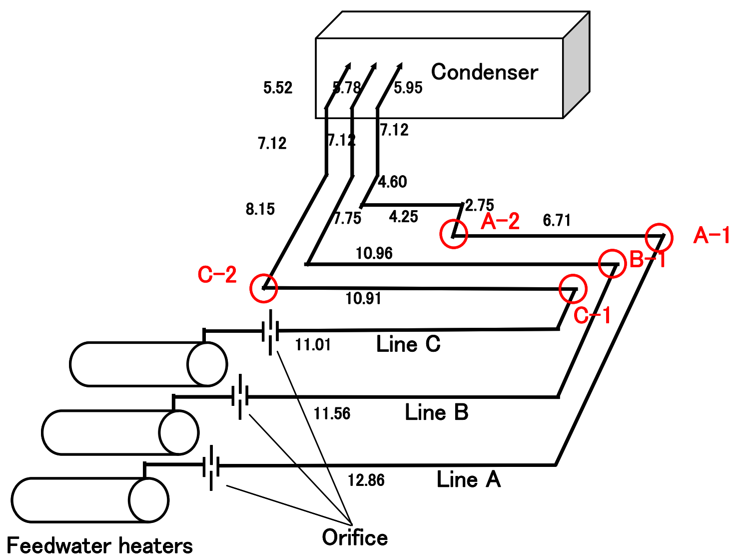

Figure 4 Feedwater heater vent lines.

Table 1 Major constants of the vent line of the plant

Items	Plant constants	Remarks
Pressure and temperature at orifice inlet	0.28 MPa, 132 °C	Choking
Mist content at the orifice	high (max 5 % assumed)	
Pressure in the condenser	0.005 MPa	No choking
Flow rate	0.21 kg/s	
Average velocity at the bend	100-180 m/s	
Average mist diameter	100 µm	
Vertical component of collision velocity	<100 m/s	

At first, 1D flow dynamics calculation is made along the flow path from the feedwater heater to the condenser in order to obtain an averaged flow distribution.

3D flow dynamics calculation by OpenFOAM [11] with the standard k-ε model is made in order to obtain a flow distribution at the bends of each line. The pipe configuration at a bend is shown in Fig. 5. The z-axis is parallel to the major flow direction. At the inlet boundary, the flow velocity calculated by the 1D flow dynamics code is adopted as inlet flow velocity.

Liquid droplet trajectories are tracked based on the flow velocity distributions calculated by the 3D flow dynamics code. Trajectory tracking of liquid droplets provides number density and velocity of liquid droplets colliding onto the pipe wall.

Wall thinning rates due to LDI (erosion) are calculated by means of Eq. (1) adopting number density and velocity of liquid droplets colliding onto the pipe wall calculated by trajectory tracking. Wall thinning rates due to LDI (corrosion) are also calculated assuming that stable water film is formed on the pipe wall inner surface where liquid droplets collide.

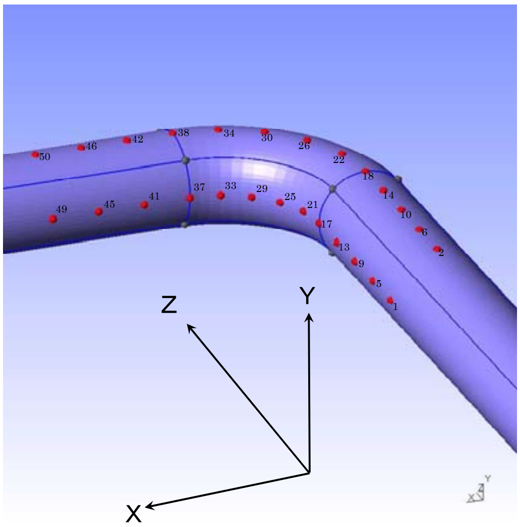

Figure 5 Pipe configuration for 3D flow dynamics calculation.

Figure 6 shows the wall thinning rates due to LDI (erosion) at the bend A-1 in Fig. 4 as a function of position on the pipe wall surface. The calculated results at the bend A-1 and the downstream of the bend A-1 are shown in Fig. 6 (a) and (b), respectively. The averaged flow velocity at the bend is 100 m/s.

The wall thinning rates due to LDI (corrosion) as a function of mass transfer coefficient are shown in Fig. 7. The temperature and pH of water are 100 °C and 7.0, respectively. Raising oxygen concentration from 1 ppb to 50 ppb reduces wall thinning rate with a order of two, though the mass transfer coefficient increases. Raising oxygen concentration contributes to generate thicker oxide layers which interrupt dissolution of iron ions into water.

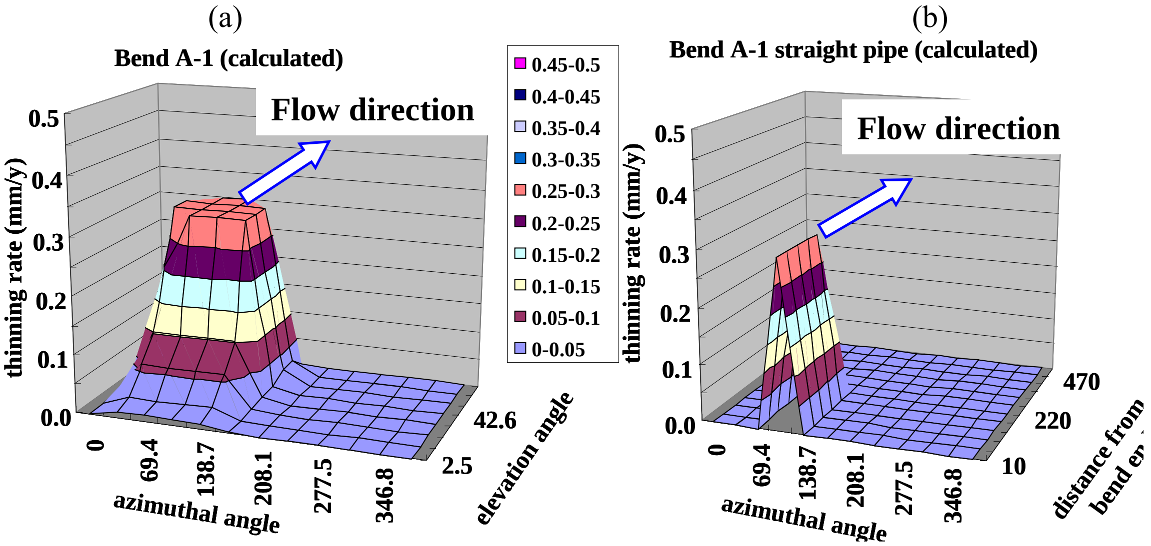

Figure 6 Wall thinning rate due to LDI (erosion) at bend A-1, (a) at bend, and (b) at downstream from bend outlet.

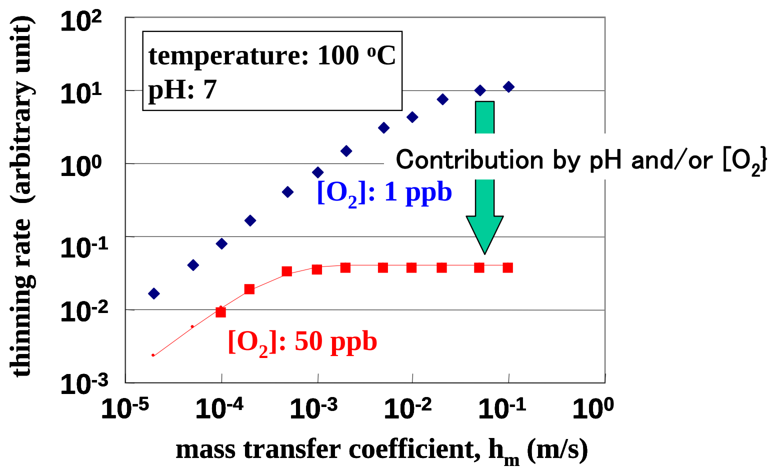

Figure 7 Wall thinning rate due to LDI (corrosion).

The wall thinning rates calculated by DRAWTHREE-LDI are shown in Fig. 8 as a function of position on the pipe wall inner surface. The wall thinning is caused due both to LDI (erosion) and LDI (corrosion).

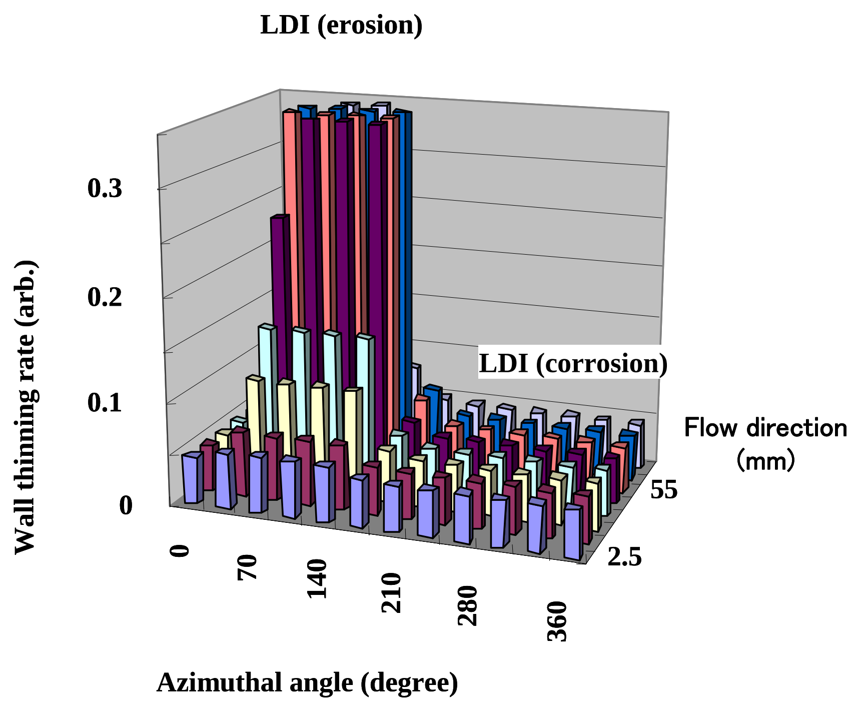

Figure 8 Wall thinning rate due to LDI.

Comparison of results calculated by DRAWTHREE-LDI with those measured at an actual power plant is shown in Fig. 9. In Fig. 9 (a) and (b), comparisons are made for LDI (erosion) and LDI (corrosion), respectively. Their standard deviations are depicted with error bars. Though there are some comparison results beyond a factor of two, which is the target in the development of DRAWTHREE-LDI [5], most calculated results agree with those measured within a factor of two.

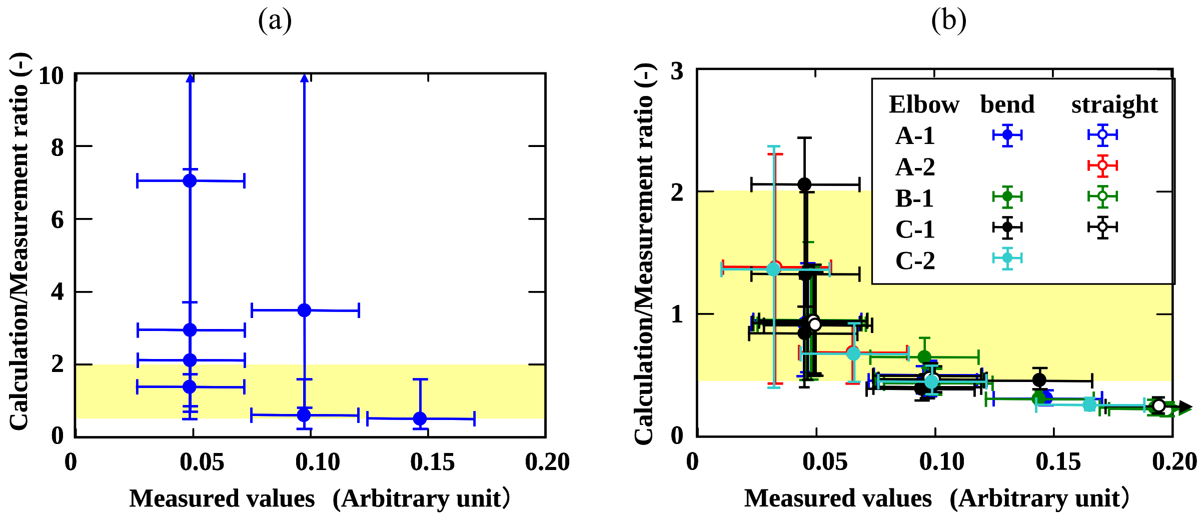

Figure 9 Comparison of results calculated by DRAWTHREE-LDI with those measured at an actual power plant, (a)LDI (erosion), and (b)LDI (corrosion).

In order to improve the accuracy of estimation by LDI (erosion), it is important to evaluate flow conditions in feedwater heater vent lines, that is, to evaluate distributions of flow velocity, quality, and number density of droplet along the vent lines. Since it is difficult to evaluate flow conditions at the inlet of a vent line, it is necessary to investigate flow conditions in parametric methods.

For improvement of accuracy of estimation by LDI (corrosion), it is important to evaluate distributions of flow velocity, oxygen concentration, and pH in the liquid film generated on the pipe wall surface.

3. Conclusion

The validations on DRAWTHREE-LDI were made through the comparisons of results calculated by DRAWTHREE-LDI with those measured in the feedwater heater vent lines at the actual power plant.

Most calculated results agreed with those measured within a factor of two which is the target in the development of DRAWTHREE-LDI, though there were some comparison results beyond a factor of two.

For LDI (erosion), it is important to evaluate distributions of flow velocity, quality, and number density of droplet along the vent lines. For LDI (corrosion), it is important to evaluate distributions of flow velocity, oxygen concentration, and pH in the liquid film generated on the pipe wall surface.

The development of the analysis model was supported by the Innovative and Viable Nuclear Energy Technology Development Project of the Ministry of Economy, Trade and Industry (2005-2007). The evaluation of the model was partially carried out under the project sponsored by the Nuclear and Industrial Safety Agency (NISA). The authors express their sincere thanks to the owners group of electric power plants in Japan for supplying plant data for the evaluation.

4. References

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