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Analysis of Fluid Characteristics in AFWS by Coupling Strategy using One-Dimensional and Three-Dimensional CFD Methods

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1. Introduction

The auxiliary feed water system (AFWS) in pressurized water reactor is a safety related system that maintains an inventory in the secondary side of the steam generators to ensure a heat sink for the removal of reactor decay heat. Thus, the proper operation of AFWS is critical to prevent core from melting in the pressurized water reactors [1]. For the required operation of AFWS, AFW pumps should be maintained within the proper level of the hydraulic performance. For this reason, there is a recirculation line for AFW pump to verify the hydraulic performance, e.g. differential pressure and flow rate which is normally measured by orifice flowmeter. In this study, the fluid characteristic nearby orifice flowmeter is analyzed by 1D and 3D numerical code. One-dimensional numerical approach is one of common methodology for evaluating hydrodynamic characteristics of systems in nuclear power plant [2-3]. It is analyzed by empirical correlations with parametric geometry model, but 1D approach has a limitation on analyzing three-dimensional effect which is caused by geometry or shape. One-dimensional numerical model was simulated with data, e.g. geometry data and component performance data of AFWS and 1D numerical model was also simulated with the friction data of orifice plate which was modified by 3D CFD results.

2. Methods and Results

2.1 1D Simplified CFD Method

Flowmaster, one-dimensional commercial CFD code, was used for modeling of fluid characteristics in AFWS. As AFWS consisted of main line and recirculation line, only recirculation line was modeled in this study. A real geometry and simplified schematic diagram of a recirculation line has been produced and is presented in Fig. 1.

The system consists of a centrifugal pump, orifice flowmeter, bypass orifice, valves, elbows and pipes. One-dimensional model of AFWS commences at the suction of auxiliary feedwater pump with proper straight pipeline and terminates the upstream of AFW storage tank. Both the inlet and outlet boundary conditions are specified as a constant total pressure representing the local system pressure. The main line is modeled as simple ended boundary.

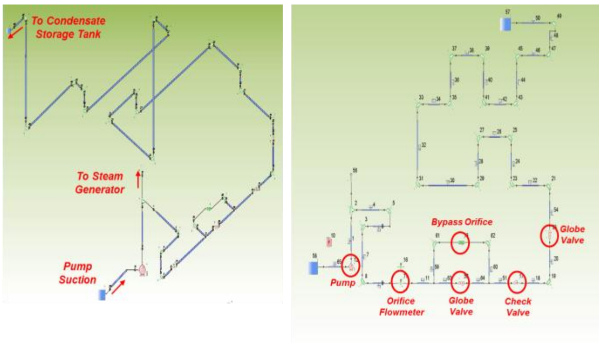

Fig. 1 Real geometry (left) and simplified schematic diagram (right) of a recirculation line in AFWS

2.2 3D CFD Analysis for Orifice Flowmeter

As a friction through the orifice flowmeter in AFWS is a substantial portion of total pressure drop, the correct calculations of loss coefficient for the orifice is important. However, in one-dimensional code, a fully developed flow condition was assumed, and predictions could be wrong if three-dimensional effect was not considered in complex arrangement.

For this reason, 3D CFD calculations were carried out with Fluent v6.2 code. As the main objective was to analyze flow characteristics and estimate loss coefficients through the orifice, the computational domain was only focused on pipes nearby the orifice plate include two elbows in the same plane. The computational domain is illustrated in Fig. 2. The realizable k-ε model with 1.3 million cells was used on the basis of the previous study [4]. The enhanced wall treatment was also considered with corresponding grid size base on the wall y+.

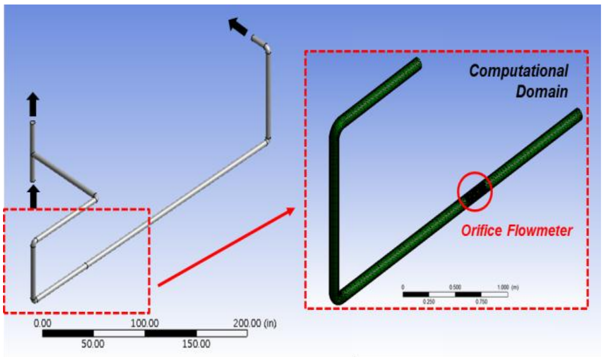

Fig. 2 Computational domain

2.3 Calculation of Loss Coefficients using 3D CFD

Generally, loss coefficient of orifice plate was defined by contraction coefficient which means the area ratio between orifice and vena contracta. (See below equation)

$$K = [1 - (d_0/D)^2 C_c]^2 \frac{1}{(d_0/D)^4 C_c^2} \qquad (1)$$

$$C_c = \frac{A_{vena}}{A_{orifice}} \qquad (2)$$

where d_0 and D are orifice and pipe diameter, and C_c is contraction coefficient.

The contraction coefficient for estimating a loss coefficient was calculated using 3D CFD results. The streamline distributions are represented in Fig. 3. It is shown that recirculation zones in the downstream region of the orifice plate are asymmetrical, because the inlet flow conditions are not sufficiently fully developed. Thus, the contraction coefficient is lower than fully developed condition which is assumed in one-dimensional code.

Fig. 4 shows parameter definitions for estimating each coefficient. The location of vena contracta was assumed a half distance from orifice plate, and coefficients were calculated by Eq. (1) and (2). The results are summarized in Table I. The original and modified methods mean Flowmaster's original and the present manner, respectively. The contraction coefficient tended to estimate 3.9% lower, and the loss coefficient calculated 15.4% higher.

In the same way, flow rates of AFWS were predicted by changing contraction coefficients as shown in Fig. 5. The x-axis indicates a contraction coefficient and the y-axis is a change of flow rate in AFWS. It is presented that a flow rate in AFWS can be changed from -10.0% to +2.0%, as contraction coefficients are ranged between 0.5 and 0.8.

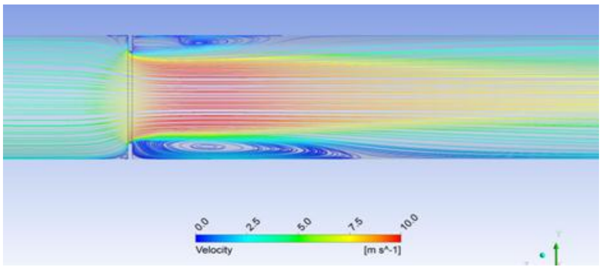

Fig. 3 Streamline distribution through the orifice plate

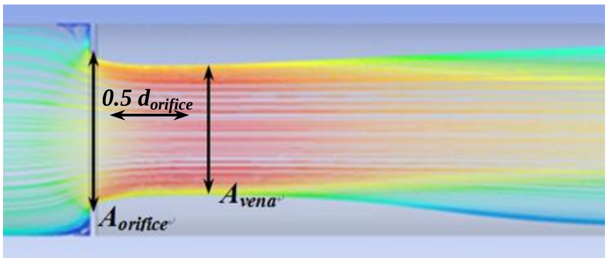

Fig. 4 Streamline distribution without secondary flow

Table I: Results Summary

	Original Method	Modified Method	% Change
Contraction Coefficient	0.6919	0.6649	-3.9%
Loss Coefficient	2.471	2.851	+15.4%

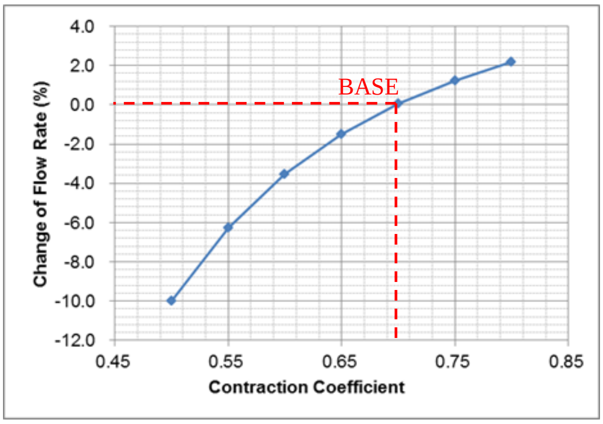

Fig. 5 Change of flow rate in AFWS according to contraction coefficient

3. Conclusions

The present study shows that the coupling strategy for simulating of auxiliary feedwater system in typical pressurized water reactor using one-dimensional and three-dimensional numerical method. In the first part of the work, a real geometry and performance data of each component were modeled by 1D commercial software, Flowmaster. Then a friction model of orifice flowmeter was modified by calculated results of 3D CFD code, Fluent. As a result, the present analysis method was sufficient to consider three-dimensional effect caused by installed position of the orifice. And it can be used to precise predictions for the purpose of audit calculations.

REFERENCES

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