Adequacy Review of Upstream Straight Lengths for Orifice Plates Recommended in KEPIC MPT-19.5; Single 90 Degree Bend Case

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1. Introduction

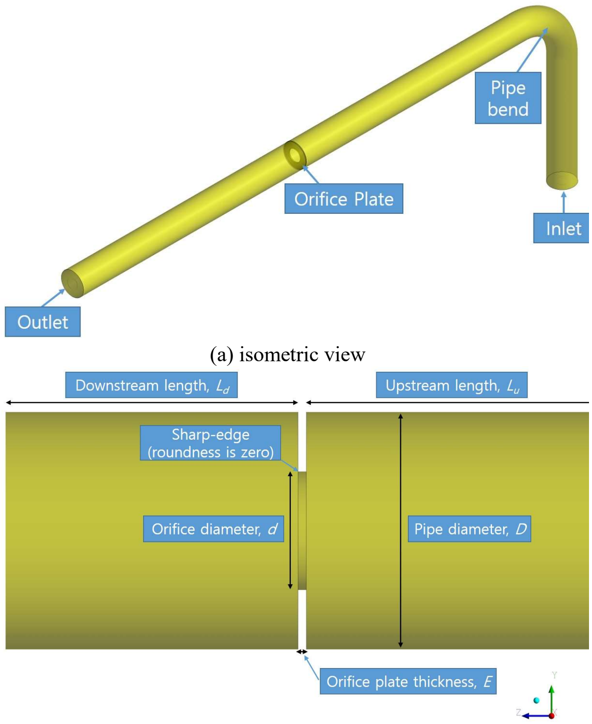
Domestic nuclear power plants are carrying out In-Service Test (IST) to check safety functions of safety-related pumps and monitor/evaluate the degree of vulnerability over time during reactor operation. When performing this pump IST, it is necessary to measure the differential pressure at the test flow rate indicated on the differential pressure type flowmeter, and check whether the corresponding differential pressure magnitude meets the acceptance criteria [1]. Therefore, it is essential to confirm whether a differential pressure type flowmeter, such as a flat orifice flowmeter, indicates the correct flow rate under wide operating conditions.

When the flow passes through the pipe bend, the region with higher axial velocity shifts to outside of pipe due to the centrifugal force. If the straight length downstream of the pipe bend is not sufficiently long, flow with the skewed (distorted) velocity profile, different from the fully developed one, may enter the hole of orifice and consequently, degrade the accuracy of an orifice flowmeter. In this connection, KEPIC MPT-19.5 [2] (2015 edition) recommended straight lengths for orifice plate on three different pipe bends configurations; (1) single 90° degree bend or tee, (2) two or more 90° degree bends in the same plane, and (3) two or more 90° degree bends in the different plane. Though KEPIC MPT-19.5 [2] (2015 edition), equivalent to ASME PTC 19.5 (2004 edition), suggested much stricter criteria for straight lengths for orifice plate in comparison with ASME PTC 19.5 (1972 edition), it is required to assess whether these criteria are appropriate.

Though recently licensing applications supported by using computational fluid dynamics (CFD) software are increasing for IST-related problems, there is no domestic regulatory guideline for the comprehensive evaluation of CFD software. Therefore, from the nuclear regulatory perspective, it is necessary to perform the systematic assessment and prepare the domestic regulatory guideline for checking whether valid CFD software and the numerical modeling is used for IST-related problems.

In this study, to assess the adequacy of upstream straight lengths for orifice plates recommended in KEPIC MPT-19.5, numerical simulation of flow inside single 90° degree bend with orifice plate was conducted with commercial CFD software, ANSYS CFX R18.1.

2. Analysis Model



(a) isometric view

(b) y-z plane view

Fig. 1. Schematic diagram for the analysis model.

As shown in Fig. 1, single 90° degree bend with orifice plate was used as an analysis model. 25°C water was used as a working fluid. Geometrical specification for the analysis model was summarized in Table I. Except upstream straight length (L_u), the magnitudes of other parameters were fixed in this study. In case of upstream straight length (L_u), its magnitudes varied from 5D to 100D. Reynolds number based on the pipe diameter and inlet velocity was about 7.2×10^4.

Table I: Geometrical specification for the analysis model.

Parameters	Unit	Magnitudes
Pipe diameter (D)	mm	100
Orifice diameter (d)	mm	50
Diameter ratio (β=d/D)	-	0.5
Orifice plate thickness (E)	mm	3.5
Radius of curvature (R_c)	mm	200
Upstream straight length (L_u)	mm	5D, 10D, 15D, 20D, 30D, 40D, 50D, 60D, 70D, 80D, 90D, 100D
Downstream straight length (L_d)	mm	10D

3. Numerical Modeling

The validity of the numerical modeling applied in this study can be found in the author's previous study [1].

3.1 Numerical Method

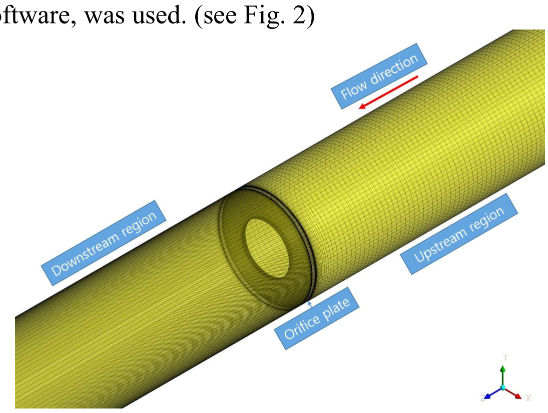
The flow inside single 90° bend pipe with square-edge orifice flowmeter was assumed to be steady, incompressible, turbulent flow. A high resolution scheme for the convection-terms-of-momentum and -turbulence equations was used to prevent the excessive numerical diffusion. The solution was considered to be 'converged' when the residuals of variables were below 10^{-6} and the variations of the target variables were small.

3.2 Turbulence Model

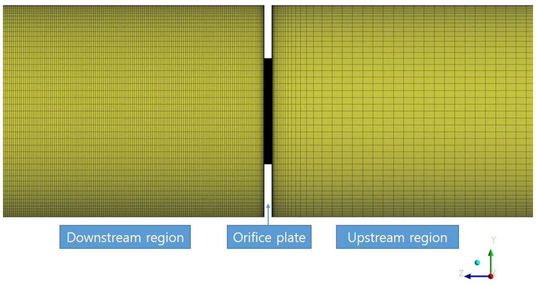
Shear Stress Transport (SST) k-ω turbulence model, which is one of Reynolds-averaged Navier-Stokes (RANS)-based two-equation turbulence models, was used to simulate complex turbulent flow inside single 90° bend pipe with square-edge orifice flowmeter. The reason is that this model may provide the improved prediction accuracy compared to the standard k-ε model under the condition where flow separation and reattachment, and re-circulation flow can exist [3].

3.3 Grid System and Boundary

To obtain the reliable prediction results by CFD analysis, it is essential to consider the use of a proper grid topology. In this study, unstructured hexahedral grid system generated by ICEM-CFD, a grid generation software, was used. (see Fig. 2)



(a) isometric view



(b) y-z plane view

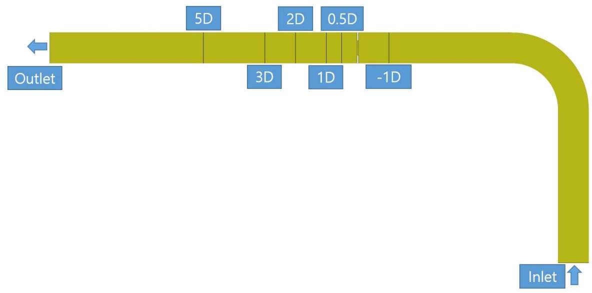
Fig. 2. Grid system.

The total number of grids used in the calculation was in the range of about between 7.6×10^{6} and 1.81×10^{7} depending on the straight length upstream of an orifice plate. To properly predict the flow distribution, dense grid distribution near the pipe wall and around the orifice flowmeter were used.

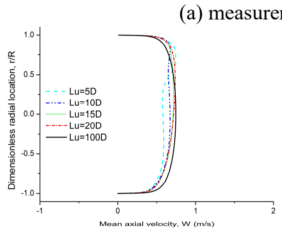
At inlet boundary, constant mass flow rate (5 kg/s) and turbulence intensity (5%) was applied. The 'average pressure over the whole outlet' option; with a relative pressure of 0 Pa, was used as an outlet boundary condition. No-slip condition was applied at the solid wall. To model the flow in the near-wall region, the automatic wall treatment was applied.

4. Results and Discussion

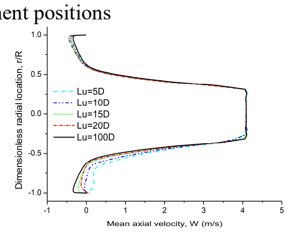
Fig. 3 shows the comparison of axial velocity profile depending on the straight length upstream of an orifice plate. When conducting the pump IST in accordance with KEPIC (or ASME) code, the location of the differential pressure taps, -1.0D and 0.5D (see Fig. 3(a)), is one of the recommended types.



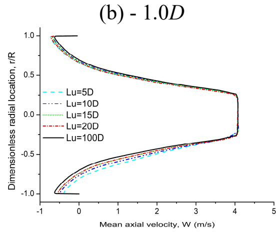
(a) measurement positions



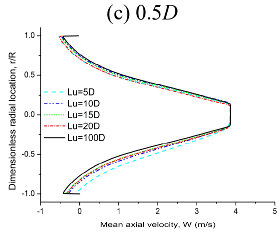
(b) - 1.0D



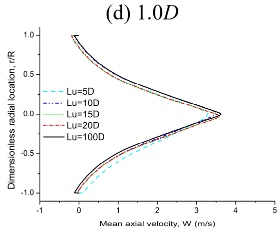
(c) 0.5D



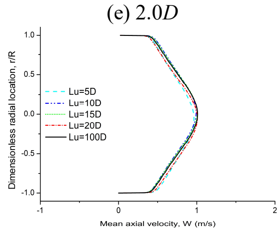
(d) 1.0D



(e) 2.0D



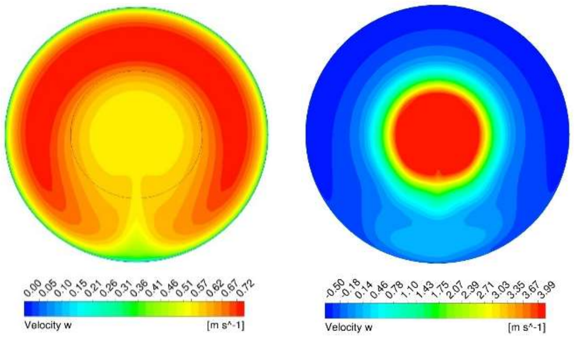
(f) 3.0D



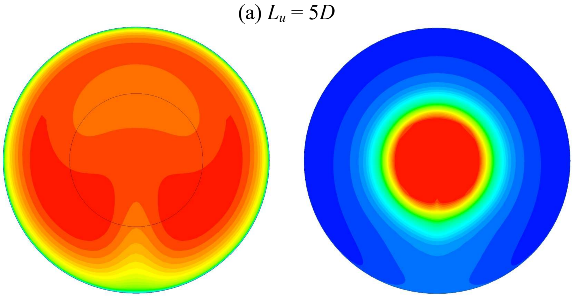
(g) 5.0D

Fig. 3. Comparison of axial velocity profile depending on the straight length upstream of an orifice plate.

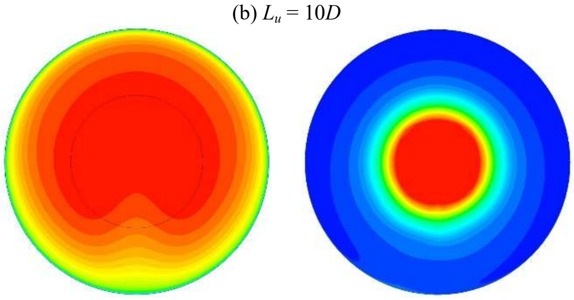
At -1.0D, axial velocity showed the skewed (distorted) profile for L_u = 5*D* and 10*D*. Though axial velocity profile was not skewed for L_u = 15*D* and 20*D*, it still had higher velocity magnitude (due to the centrifugal force) near the upper region of pipe.



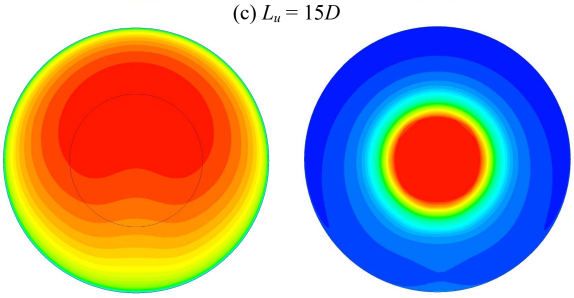
(a) L_u = 5*D*



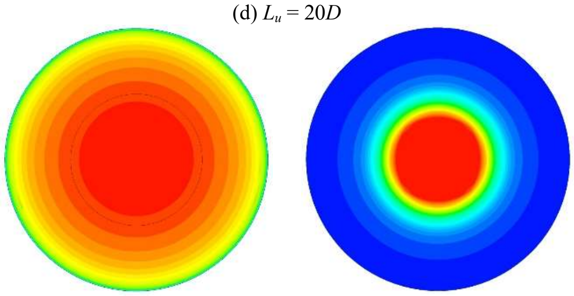
(b) L_u = 10*D*



(c) L_u = 15*D*



(d) L_u = 20*D*



(e) L_u = 100*D*

Fig. 4. Comparison of axial velocity distribution depending on the straight length upstream of an orifice plate (left; -1.0*D*, right; 0.5*D*).

This indicates that the incoming flow is not fully developed yet. For L_u = 100*D*, the fully developed flow was established. For reference, according to Table 7.1.2.1 in KEPIC MPT-19.5, the recommended upstream straight lengths for the present analysis model is 14*D*.

As the flow passed through the orifice hole and moved downstream, the difference of axial velocity profile near the lower part of pipe gradually decreased.

Fig. 4 shows axial velocity distribution at *D* from the upstream face and *D*/2 from the downstream face of the orifice plate depending on the straight length upstream of the orifice plate. As the straight length upstream of the orifice plate increased, axial velocity distribution before and after the orifice plate approached the fully developed flow pattern.

Mass flow rate through the orifice flowmeter can be calculated by using the following equation (1):

$$q_m = \frac{C_d A}{\sqrt{1-\beta^4}} \sqrt{2\rho\Delta p} \tag{1}$$

where q_m is the mass flow rate, C_d is the discharge coefficient, A is the area of an orifice hole, β is the diameter ratio, ρ is the fluid density, and Δp is the differential pressure.

Fig. 5 shows the differential pressure magnitude between *D* from the upstream face and *D*/2 from the downstream face of the orifice plate. As the straight length upstream of the orifice plate increased, the differential pressure gradually decreased and approached near the constant magnitude. However, the differential pressure near the KEPIC recommended upstream straight lengths (L_u = 14*D*) deviated somewhat from this constant magnitude.

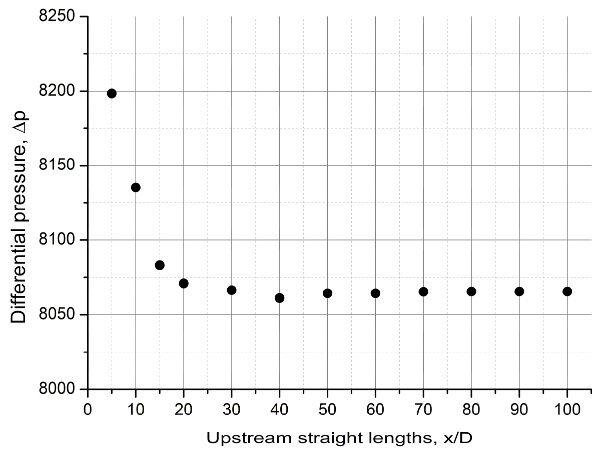


Fig. 5. Variation of the differential pressure magnitude depending on the straight length upstream of the orifice plate.

Fig. 6 shows the discharge coefficient magnitude between *D* from the upstream face and *D*/2 from the downstream face of the orifice plate. As the straight length upstream of the orifice plate increased, the discharge coefficient gradually increased and approached near the constant magnitude. Similar to the differential pressure shown in Fig. 5, the discharge coefficient near the KEPIC recommended upstream straight lengths (L_u = 14D) deviated more or less from this constant magnitude.

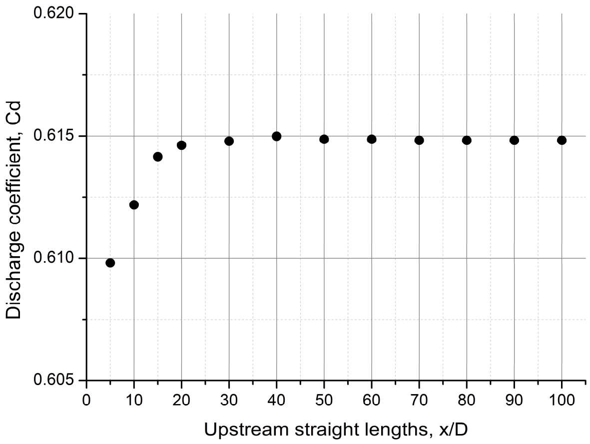


Fig. 6. Variation of the discharge coefficient magnitude depending on the straight length upstream of the orifice plate.

5. Conclusions

In this study, to assess the adequacy of straight lengths for orifice plates recommended in KEPIC MPT-19.5, numerical simulation of flow inside single 90° degree bend with orifice plate was conducted with commercial CFD software, ANSYS CFX R18.1. Main conclusions can be summarized as follows:

(1) As the straight length upstream of the orifice plate increased, axial velocity distribution before and after the orifice plate came close to the fully developed flow pattern. In addition, the differential pressure and discharge coefficient gradually approached near the constant magnitude.

(2) Though KEPIC MPT-19.5 (2015 edition) suggested much stricter criteria for straight lengths for orifice plate in comparison with ASME PTC 19.5 (1972 edition), it could not guarantee the fully developed orifice incoming flow. Therefore, it is at least required to obey the straight length for orifice plate (diameter ratio β = 0.5) recommended in KEPIC MPT-19.5, and if possible, it may be essential to secure the longer straight length.

ACKNOWLEGEMENT

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