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Preliminary Study for a Numerical Investigation on the Effect of an Upstream Elbow on an Orifice Flowmeter Performance

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1. Introduction

In a previous work [1], we tested various turbulence models for simulating the flow through an orifice flowmeter under an assumption that the flowfield is axisymmetric. We concluded that Wilcox's k-ω model shows the best performance for this flowfield among the chosen two-equation turbulence models, but it still requires a modification for an accurate prediction. Another question however has arised after the numerical simulation of the orifice flow.

There are recommendations for an installation of orifice flowmeters to measure the flowrates accurately. In many field installations, these requirements are difficult to be met. To reduce the installation effects, many flow conditioners, which shorten their length to achieve fully developed flow conditions, have been developed. To overcome these effects, it is possible to modify the discharge coefficient of orifice flowmeters by a suitable correction that is deduced by an understanding of the flowfields.

In this paper, we attempt to numerically simulate installation effects by adding an elbow upstream of an orifice flowmeter. We hope that several simulations help us estimate the effects of the distance between the elbow and the orifice flowmeter on the orifice performance.

2. Methods and Results

2.1. Computational methods

FLUENT [2], a commercial computational fluid dynamics program, is used to simulate the flowfield. A computational domain is constructed to include an elbow and an orifice flowmeter. A three dimensional simulation is required due to the computational domain.

Figure 1 shows a schematic diagram for the computational domain. The 90° elbow that has a 2D radius of curvature is placed in the computational domain. At the upstream of the elbow, 40D of a straight pipe is placed to obtain a fully developed flow condition. A straight pipe of a specified length and an orifice flowmeter are placed at the elbow downstream. An additional 40D straight pipe is attached behind the orifice flowmeter. To compare the effects of the elbow locations from the orifice on the performance of the orifice flowmeter, the simulations are conducted for cases where the elbow is placed at 5D and 10D upstream of the orifice, respectively. To obtain a pressure drop due to the orifice only, cases that have no elbow are also simulated. The orifice plate has 1/8 in. of thickness and β= 0.5. The last half thickness of the orifice plate is beveled with a 45 degree. The tube diameter is 50.8 mm. Total number of nodes in the computational grids are over a half million.

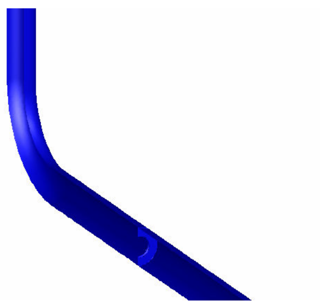


Figure 1. Schematic diagram for the computational domain

Even though the model performance among the two-equation turbulence models is not best, we selected the standard k-ε turbulence model for the simulation because this model converges enough to obtain meaningful results. The standard wall function is adopted as a wall boundary condition for the turbulence quantities.

2.2. Results

We conducted a series of simulations for different Reynolds numbers (50,000 and 100,000). The result from a simulation without an elbow is also presented for a comparision. Performance of the orifice flowmeter is judged by a consistent pressure drop for a given flow rate. Pressure drop is measured between 4D upstream and 6D downstream from the orifice plate.

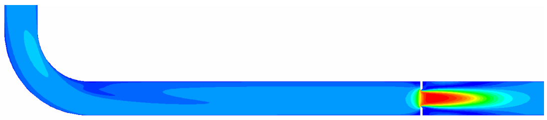
Table 1 shows the comparison of the estimated pressure drop across the orifice plate. As the distance between the elbow and the orifice plate decreases, the estimated pressure drops due to the orifice increase for both Reynolds numbers simulations. In contrast, variation percentages of the pressure drop due to the

Elbow position	$Re=5\times10^4$	$Re=1\times10^5$
No-elbow	12.9 kPa	51.8 kPa
5D-upstream-elbow	13.6 kPa (+5.7%)	54.7 kPa (+5.7%)
10D-upstream-elbow	13.2 kPa (+2.3%)	52.9 kPa (+2.2%)

Table 1. Pressure drops and its variation with respect to without-elbow case.

(a) No-elbow, Re=5×10^4

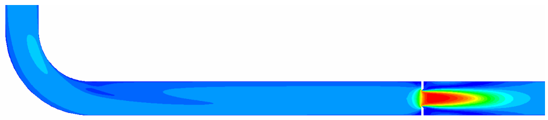
(b) 5D-upstream-elbow, Re=5×10^4



(c) 10D-upstream-elbow, Re=5×10^4

(d) No-elbow, Re=1×10^5

(e) 5D-upstream-elbow, Re=1×10^5



(f) 10D-upstream-elbow, Re=1×10^5

Figure 2. Velocity magnitude contour on the symmetric plane

Reynolds number are not changed considerably. This independency on the Reynolds number has to be checked with a wider range of simulations. The percentage of a variation in the pressure drop is found to be less than 6% in this research and it means that the orifice flowmeter in this configuration indicates a 3% higher flowrate when it is compared with a correctly installed one. We can expect that this effect will be stronger as the distance between the elbow and the orifice is shortened.

Morrison et al. [4] performed an experimental study to quantify the effect of an orifice inlet velocity profile. They claimed that the following quantity can be used to correct the discharge coefficient when a velocity profile differs from a fully developed condition.

$$\int_0^R \int_0^{2\pi} \rho u^2 r^2 d\theta dr \qquad (1)$$

They explained that the change of a pressure drop is due to a change of the momentum at the outer portion of a pipe.

Figure 2 shows the velocity magnitude contour on the symmetric planes. From this figure, we can observe that the velocity profiles of the cases with the elbow are different from the fully developed conditions and that the 5D-upstream-elbow case shows a larger difference than the 10D-upstream-elbow case. In both cases the distorted velocity profiles, especially near the upper wall, still remain even at just upstream of the orifice. It is also observed that a shorter distance causes a higher distorted velocity profile. This means that distorted flowfields cause inaccurate velocity measurements by an orifice flowmeter. This phenomenon can be explained by a similar mechanism that Morrison et al. described.

3. Conclusion

Effect of an upstream elbow on an orifice flowmeter performance is investigated by numerical simulations. The shorter the distance between the orifice and the elbow is, the higher the estimated pressure drop across the orifice plate is. This result is consistent with previous experiments that were conducted by other researchers. Reynolds number has no effect on the variation percentages of the pressure drop.

For the convergence problem we only evaluated the standard k-ε turbulence model. Judging from previous experience, prediction of an effect of an upstream elbow on an orifice flowmeter performance may vary due to the selected turbulence model. This dependency needs to be checked in the future.

REFERENCES

[1] S. H. Kim, J. Yoon, Comparison of Turbulence Models for Simulation of Flow around an Orifice Flowmeter, KNS Fall Conference, 2006.
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