Comparison of Turbulence Models for Simulation of Flow around an Orifice Flowmeter

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1. Introduction

An orifice flowmeter is widely used to measure a flow rate in a pipe in various applications due to its simplicity. From the view point of a fluid flow, a flow around an orifice flowmeter is very complex and hard to measure its flow pattern. There is a velocity increase upstream of the plate. The flow is accelerated due to a contraction of the flow area around the plate and is decelerated after the orifice bore. Due to a sudden change of the flow area the flow shows complex flow patterns. It has been reported that two-equation turbulence models can not predict a flow with a sudden change of flow configurations. In this study various turbulence modes are tested and compared for the orifice flow field.

2. Methods and Results

The simulation was conducted by using a commercial computational fluid dynamics code, FLUENT [1]. This code provides several options for turbulence models and their boundary conditions. Within these models, we tried to verify the turbulence model capability for a simulation of a flow around an orifice flowmeter.

2.1 Turbulence models

In this study, we selected the following turbulence models: Spalart-Allmaras [2], standard k-ε [3], RNG k-ε [4], Realizable k-ε [5], Wilcox k-ω [6], SST k-ω [7] models.

The simplest complete turbulence model in FLUENT is the Spalart-Allmaras model, which solves a turbulence viscosity by itself and therefore requires less computational resources than conventional two-equation turbulence models.

A turbulence model that is set as a default in FLUENT is the standard k-ε model, which solves two transport equations for the turbulence kinetic energy and its dissipation rate. The standard k-ε model has been tested for various flow configurations and it was concluded that this model shows excessive diffusion for a flow with large strain rates. To overcome these shortcomings, there are several variances of the standard k-ε model. FLUENT provides the RNG k-ε model and the realizable k-ε model among them.

Instead of solving the dissipation rate, another turbulent quantity can be selected to calculate the turbulent scales with a combination of the turbulence kinetic energy. Typical examples of this type of model are Wilcox's k-ω model and SST k-ω model. These models solve a transport equation of the specific dissipation rate.

Boundary conditions for the turbulence models have several options when k-ε type models are used. The standard wall function and the enhanced wall treatments are selected to examine the influence of the turbulence model boundary conditions.

2.2 Computational domain

Morrison et al. [8] conducted an experiment to measure the mean velocity and turbulence fields inside a beta=0.50 orifice flowmeter operating at a Reynolds number of 91,100 by using a three-color, 3-D laser Doppler anemometer system. The thickness of the orifice plate is 1/8 in. The last half thickness of the orifice plate is beveled with 45 degree. The tube radius is 25.4 mm.

The computational domain is axisymmetric and upstream and downstream lengths of the domain from the orifice plate are 80 pipe radii and 40 radii, respectively. The upstream length is long enough that the flow becomes a fully developed condition before reaching the plate.

Each boundary condition for the turbulence models has its own limitation for the height of the computational grid that is attached to the wall. The grid is constructed to meet the requirement for the first grid off the wall.

2.3 Results

Table 1 compares the pressure drop and reattachment points of the measurement and simulation results. Following the experimental setup, the pressure drop is a pressure difference between 8 radii upstream and 12 radii downstream of the orifice plate. Predictions of the reattachment point are also compared.

Table 1. Pressure drop and Reattachment point

Model	ΔP (kPa)	Reattachment Point
Measurement		5.3 R
Spalart Allmaras	12.6	7.6 R
Standard k-ε	11.0	3.6 R
RNG k-ε	12.6	7.0 R
Realizable k-ε	12.6	6.8 R
k-ω	11.7	6.6 R
SST k-ω	12.5	6.9 R

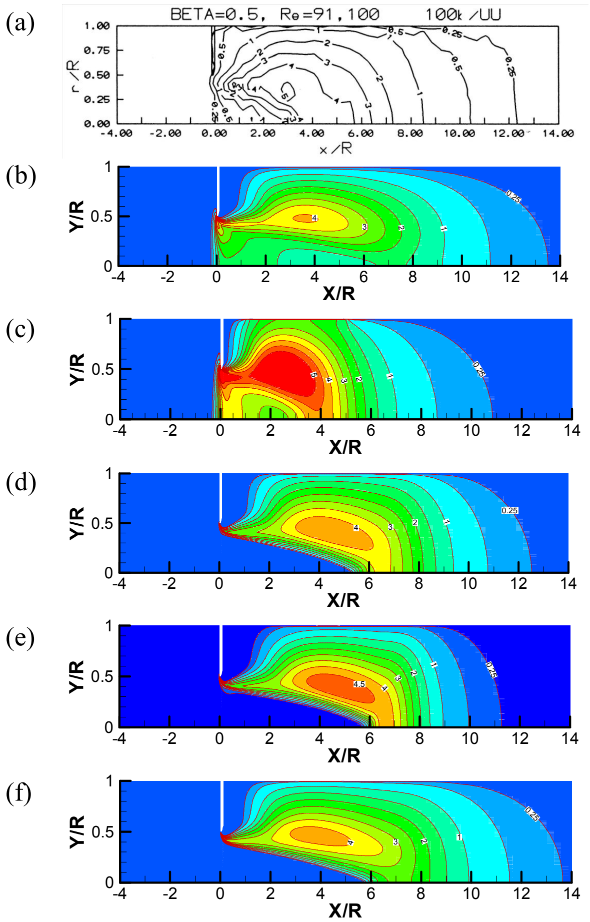

Figure 1. Turbulence kinetic energy, 100 k/U^2.
(a) Measurement, (b) k-ω, (c) standard k-ε, (d) RNG k-ε, (e) Realizable k-ε, (f) SST k-ω.

As is shown in the table, the reattachment point predictions are different from the measurement. Especially, the standard k-ε model predicts a shorter recirculation zone and a lesser pressure drop than the others. The other models show similar lengths of the recirculation zone. Among them, the Spalart-Allmaras model shows the longest length. Wilcox's k-ω model makes the closest prediction.

The reason that the predicted recirculation zone is different from the measurement can be explained by examining the turbulence kinetic energy distribution (Figure 1). The Spalart-Allmaras model did not solve the turbulence kinetic energy, so we can not include it in Figure 1. The standard k-ε model predicts the highest turbulence kinetic energy level among the selected turbulence models. High turbulence kinetic energy means a high diffusion of the momentum and a reduced length of the recirculation region. This result is consistent with the known shortcomings of a high diffusivity of the standard k-ε model in predicting high strained flows. The RNG and realizable k-ε modes show a lower level of the turbulence kinetic energy than the standard k-ε model. But, these models also reduce the kinetic energy near the orifice bore, which is shown in the measurement. The SST k-ω predicts it in a similar way.

The Wilcox k-ω model shows the closest prediction, except for a lower level and a peak location of the turbulence kinetic energy. A reduced turbulence kinetic energy near the orifice bore is also predicted. The length of its recirculation zone is the most accurate.

3. Conclusion

Several two-equation turbulence models are tested for a flow around an orifice flowmeter. The prediction shows that the selected turbulence models failed to accurately predict the length of the recirculation zone. This means that these models can not predict the pressure drop accurately. Among the models, the k-ω model is the most promising candidate for simulating a flow around an orifice flowmeter. However, this model still requires an appropriate modification, and it remains as a future work.

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