Computational Analysis for Pressure Loss Coefficient in a Sudden Contraction and Double Expansion

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1. Introduction

One of the important tasks in the design activities is to accurately predict the pressure losses and flow distribution in the reactor. This is essential to ensure a uniform flow distribution in the reactor and to identify the pump requirements. This task can be challenging especially when facing configurations with no empirical correlations available in the literature. An example of such challenges encountered in the design activity is a region in the flow path which undergoes a sudden contraction followed by a double expansion.

In this paper, with the aim of estimating the appropriate orifice size corresponding to the targeted pressure drop, the flow in the above mentioned region is investigated numerically and representative results are presented.

2. Methods and Results

In this section the method and steps followed to conduct the simulation are described. Initially, an existing empirical correlation was used to identify the appropriate turbulence model. Then, a grid sensitivity analysis was conducted using four different grids with different mesh resolutions. Finally, pressure loss coefficients for various orifice diameters were analyzed to develop the empirical correlation.

2.1 Computational Setup

Computational Fluid Dynamics (CFD) analyses were conducted using FLUENT 12.0 code [1] by applying the configuration in Fig. 1. The following basic assumptions were made in the CFD model: 1) steady-state, axisymmetric, incompressible, isothermal, and fully turbulent flow; 2) gravity effect ignored; 3) constant-property Newtonian fluid. The simulations were carried out using a segregated and double precision solver with SIMPLE algorithm for pressure-velocity coupling, second order upwind method for discretization, and standard wall function for near wall treatment. As to the boundary conditions, mass flow rate was prescribed at the inlet with a Reynolds number of 3.14×10^6, an outflow boundary was applied at the outlet, and the no-slip condition was imposed on all solid walls.

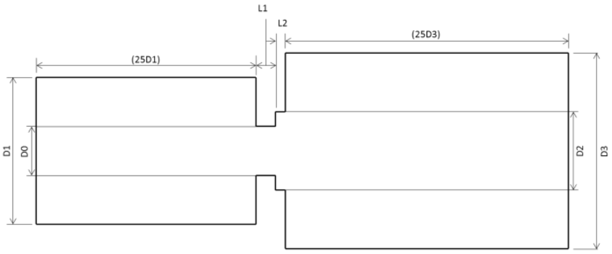

Fig. 1. Computational domain used in CFD analysis.

2.2 Turbulence model verification

To identify the appropriate turbulence model, the configuration was simplified to a sudden contraction and a sudden expansion (i.e., $D_2 = D_0$), in which the existing correlations can be applied. Four different turbulence models including; RNG k-ϵ, Realizable k-ϵ, Standard k-ω, and SST k-ω, were tested. The empirical correlation for the pressure loss coefficient in an orifice plate is given by [2]:

$$\zeta_o = 0.5\left(1-\frac{F_0}{F_1}\right)^{0.75} + \tau\left(1-\frac{F_0}{F_2}\right)\left(1-\frac{F_0}{F_1}\right)^{0.375} + \left(1-\frac{F_0}{F_2}\right)^{2} + \lambda\frac{L}{D_0} \quad (1)$$

where ζ_o is the pressure loss coefficient based on the orifice diameter D_0, F_0 is the area of the orifice, F_1 is the area of the contraction joint at the inlet, F_2 is the area of the expansion joint at the outlet, L is the orifice length, τ is the adjustment factor, and λ is the friction factor.

The results of empirical correlation and the four turbulent models are shown in Fig. 2. The SST k-ω model is shown to be the best model that matches the empirical correlation with error less than 0.5%. Therefore, it was selected as the optimum turbulence model to complete the rest of the analyses.

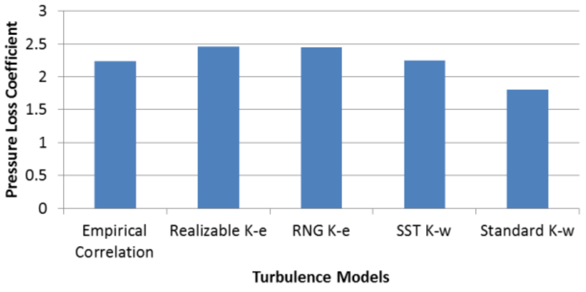

Fig. 2. Comparison of calculated pressure loss coefficient using empirical correlations and turbulence models.

Table I: Grid Information

Case	Total No. of grid points	y^+ value in the orifice
1	426800	≤ 40
2	290432	≤ 70
3	162720	≤ 90
4	94208	≤ 100

2.3 Grid Sensitivity Analysis

The grid sensitivity analysis was conducted for $D_0/D_1 = 0.226$. Four different grids with different mesh resolutions were generated and the first grid size was calculated according to the predetermined y^+ values in the orifice as shown in Table I.

The results of the grid sensitivity analysis are shown in Fig. 3. The resulting error between the four different grids was below 1%. Case 3 with 162720 grid points was selected as the optimum grid to complete the rest of the analyses.

2.4 Analysis Results

After identifying the optimum grid and turbulence model, various orifice diameters ranging from $D_0/D_1 = 0.226$ to 0.301 were analyzed using FLUENT 12.0 code. Information of the grids used in the analysis is according to case 3 shown in Table I. The pressure loss coefficient resulting from each diameter size was calculated and plotted in Fig. 4.

The correlation equation, Eq. (2), is a result of fitting a curve line through the points in Fig. 4.

$$\zeta_0 = A + B_1\frac{D_0}{D_1} + B_2\left(\frac{D_0}{D_1}\right)^2 \tag{2}$$

where coefficients are as follows: $A = 0.2533$, $B_1 = 19.4453$, and $B_2 = -42.0941$.

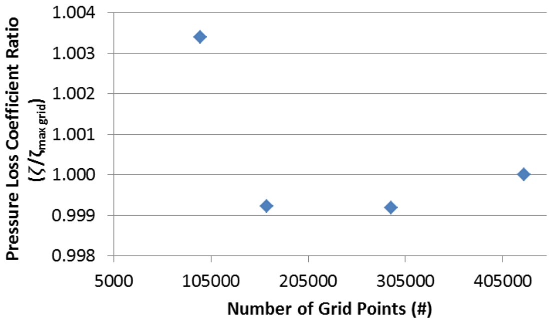

Fig. 3. Grid sensitivity analysis results.

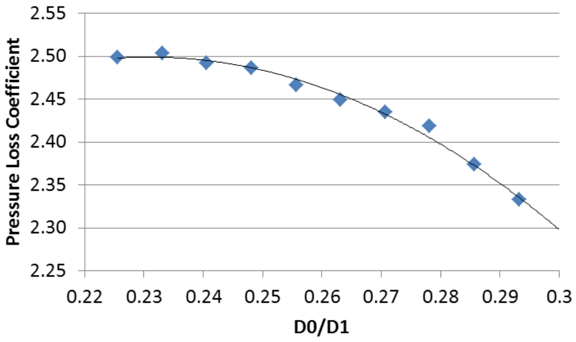

Fig. 4. Pressure loss coefficient vs. orifice diameter.

3. Conclusions

In this work, CFD analyses were conducted to develop a correlation for pressure loss coefficient for fluid experiencing a sudden contraction followed by two expansions. Sensitivity tests were also conducted to identify the proper turbulence model and to achieve a grid independent solution.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) funded by the Korea government (MSIT) (2016M2C6A1930039), in addition to funding from King Abdullah City for Atomic and Renewable Energy, Kingdom of Saudi Arabia, within the SMART PPE Project.

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[2] I. E. Idelchik, “Handbook of Hydraulic Resistance”, 3rd edition, 1997.