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CFD Calculation of Turbulent and Thermal Mixing in a T-Junction: Comparison with Vattenfall Experimental Data

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1. Introduction

High-cycle thermal fatigue is main cause of structural failures which have occurred in several nuclear power plants around the world. The mixing zones where hot and cold streams meet, particularly near T-junctions are susceptible to high-cycle thermal fatigue.

From a thermal hydraulic point of view, the accurate prediction of turbulent eddies and associated temperature fluctuations is an essential task, requiring CFD calculations and advanced turbulence modeling. Turbulence models based on RANS (Reynolds Averaged Navier-Stokes equations) which are typically used in industrial applications have difficulties to simulate realistic turbulent and thermal mixing.

In November 2008, a T-junction thermal mixing test was conducted at the Älvkarleby Laboratory of Vattenfall Research and Development (VRD) in Sweden. OECD/NEA distributed this test data to participants of the first CFD benchmark exercise project.

In this study, transient CFD calculations for Vattenfall T-junction thermal mixing test are performed to obtain the velocity and temperature at specified locations using DES-SST (Detached Eddy Simulation-Shear Stress Transport) turbulence model, and calculation results are compared with experimental data.

2. Vattenfall T-Junction Thermal Mixing Test

Cold water of 19°C is supplied through a horizontal pipe with inner diameter 140mm, and hot water of 36°C is provided from a vertically oriented pipe with inner diameter 100mm. The inlet volumetric flow rates of cold and hot water are 9 and 6 liters/s, respectively. Special care was taken to provide simple and well-defined inlet boundary conditions to remove ambiguities in defining the CFD input data.

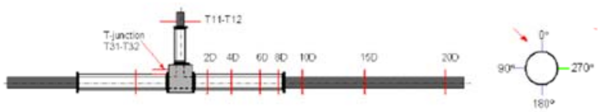

Fig. 1. Thermocouple Locations of Vattenfall Test

Temperature fluctuations near the pipe walls were measured using thermocouples located 1mm from the wall at x=2D, 4D, 6D, 8D, 10D, 15D and 20D and around circumference of the pipe as shown in Fig. 1. Velocity profiles over the pipe cross-sections at x=1.6D, 2.6D, 3.6D, 4.6D were measured using PIV.

3. Results and Discussion

3.1. Problem Definition and Methodology

The geometry of Vattenfall T-junction test is depicted in Fig. 2. In order to apply accurate inlet boundary conditions, preliminary CFD calculations are performed for horizontal and vertical pipes which are connected to cold and hot water inlet, respectively. For outlet condition, the average relative static pressure of 0 Pa is applied. No slip and adiabatic condition is specified at the wall. The DES-SST turbulence model is used to simulate turbulent and thermal mixing.

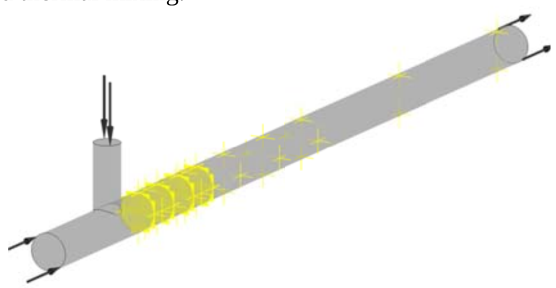

Fig. 2. Modeling of Vattenfall T-junction Test

The solution domain is divided into 2,389,592 hexahedral cells and the physical time step set to 0.001 second with ten of the maximum number coefficient iterations per time step. Convergence of the iterative computations for each time step is determined when the RMS residual of the major parameters is less than 10^{-4}.

3.2. Flow and Thermal Field in the T-junction

Figure 3 shows velocity and temperature distributions at the elapsed time of 13 sec on a y=0 plane that cut across the middle of the system. It can be seen that recirculation zone is formed at the top of the main pipe at which the branch pipe is connected. In this figure, large-scale eddy motions and thermal oscillations are predicted downstream of the T-junction. These fluctuations have a large influence on the temperature on the wall.

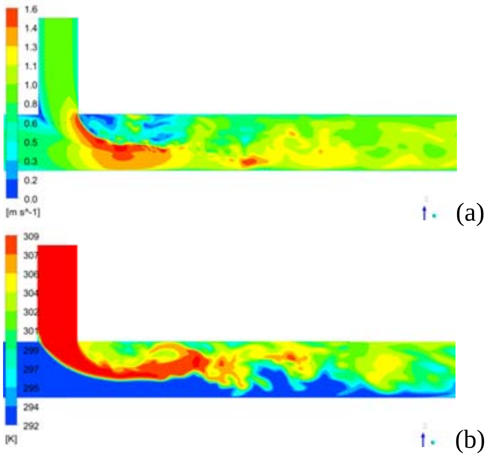

Fig. 3. Instantaneous Flow and Thermal Field in the T-junction: (a) Velocity (b) Temperature

3.3. Comparison with Experimental Data

Time-averaged velocity profiles at x/D=1.6 cross-section obtained from the calculations are compared to experimental data in Fig. 4. For z=0 plane, calculated time-averaged U has symmetric profile and agrees well with experimental data. For y=0 plane, the values are good agreement with experiment for z below the center. However, for z above the center, experiment shows the back flow zone near the wall, but code predicts only unidirectional flow. For time-averaged V and W velocities, the values are very lower than U velocity and there are some differences between experimental data and calculations.

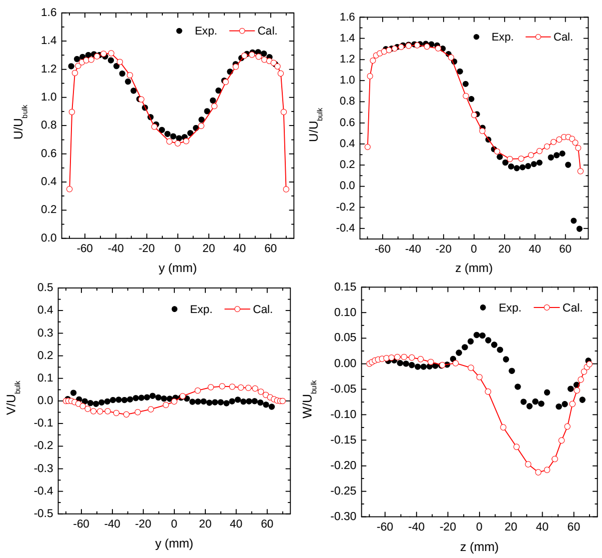

Fig. 4. Time-Averaged Velocities at x/D=1.6

Figure 5 shows non-dimensional time-averaged temperatures near the wall according to x/D. As shown in this figure, calculations results have large differences to experimental data except for bottom case at the upstream, while code predicts temperature well at the downstream. For the bottom case, at the upstream, there is no mixing between hot and cold water, therefore the value is equal to 0.

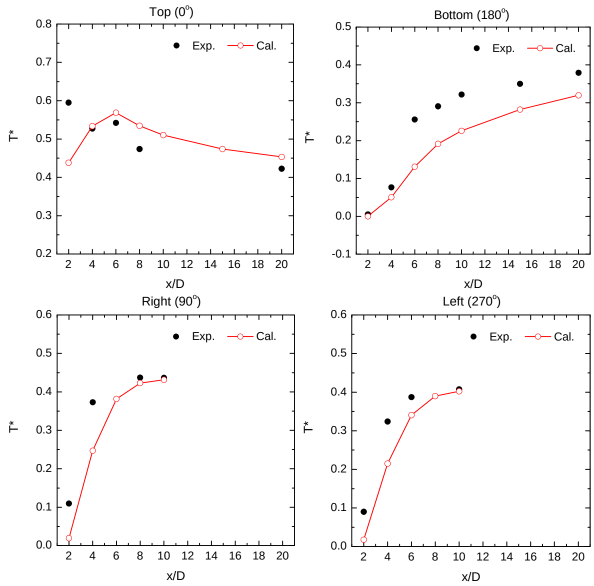

Fig. 5. Time-Averaged Temperatures near the wall

4. Conclusion

Transient CFD calculations for Vattenfall T-junction thermal mixing test are performed using DES-SST turbulence model, and calculation results are compared with experimental data. The computational results are in qualitatively good agreement with experimental data. However, calculated temperatures near the wall especially at the upstream have large difference with experimental data. Therefore, in order to predict more accurate results, LES turbulence model should be applied and comprehensive sensitivity study are needed.

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