Transactions of the Korean Nuclear Society Spring Meeting
Pyeongchang, Korea, May 27-28, 2010

CFD Calculation of Turbulent and Thermal Mixing in a T-Junction: OECD/NEA Sponsored CFD Benchmark Exercise

Dong Gu Kang*, Kwang Won Seul, Yong Ho Ryu
Thermal-Hydraulics Research Dept., Korea Institute of Nuclear Safety
**Corresponding author: littlewing@kins.re.kr*

1. Introduction

Failures of structures due to high-cycle thermal fatigue have occurred in several nuclear plants around the world, for different reactor types. Many of these have been associated with mixing zones where hot and cold streams meet, and particularly near T-junctions. An example is the failure event at the Civaux-1 PWR in France in May 1998.

As the hot and cold streams from the main and branch pipes meet, shear instabilities produce turbulent eddies, causing temperature fluctuations on the pipe walls downstream of the junction. The fluctuations induce cyclic strain variations in the pipe material, and may result in fatigue damage and cracking [1].

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.

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 reserved this test data for CFD benchmark exercise, and invited CFD simulations in May 2009.

In this study, transient CFD calculations for Vattenfall T-junction thermal mixing test are performed to obtain the temperature, velocity and turbulent kinetic energy at specified downstream locations using (U)RANS turbulence models (k-ε, SST) as well as scale-resolving SAS-SST turbulence model.

2. Vattenfall T-Junction Thermal Mixing Test

The test facility is illustrated in Fig. 1. Cold water of 19^{o}C is supplied through a horizontal pipe with inner diameter 140mm, and hot water of 36^{o}C is provided from a vertically oriented pipe with inner diameter 100mm.

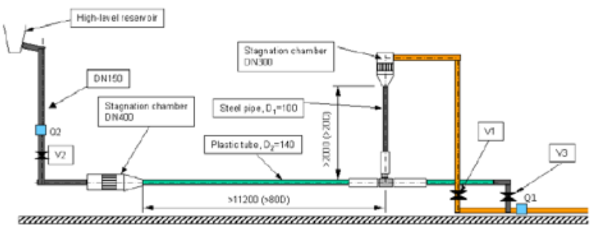

Fig. 1. Schematic of Vattenfall T-junction Test Facility

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. Temperature fluctuations near the pipe walls were measured using thermocouples located 1mm from the wall.

3. CFD Calculations

3.1. Problem Definition and Methodology

The geometry of Vattenfall T-junction test is depicted in Fig. 2. In order to find inlet boundary conditions, preliminary CFD calculations are performed for horizontal and vertical pipes which are connected to cold and hot water inlet, respectively. For inlet boundary conditions, preliminary CFD calculation results are applied, and for outlet condition, the average relative static pressure of 0 Pa is applied. No slip and adiabatic condition is specified at the wall.

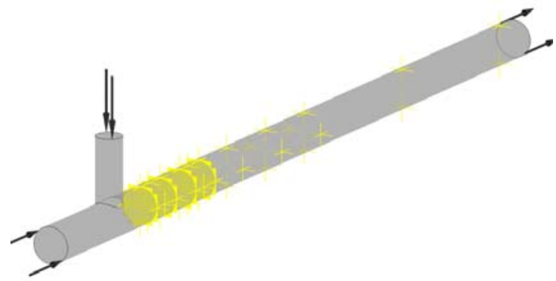

Fig. 2. Modeling of Vattenfall T-junction Test

The solution domain is divided into 1,680,000 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}.

(U)RANS turbulence models such as k-ε and SST model as well as scale-resolving SAS-SST model are used to simulate turbulent and thermal mixing.

3.2. Flow and Thermal Field in the T-junction

Figure 3 shows velocity and temperature distributions at the elapsed time of 7sec using SAS-SST turbulence model 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. The mixing of hot and cold water is delayed in that region. As the fluid flows downstream of the pipe, hot and cold water are mixed well, so that temperature on the cross-section becomes uniform.

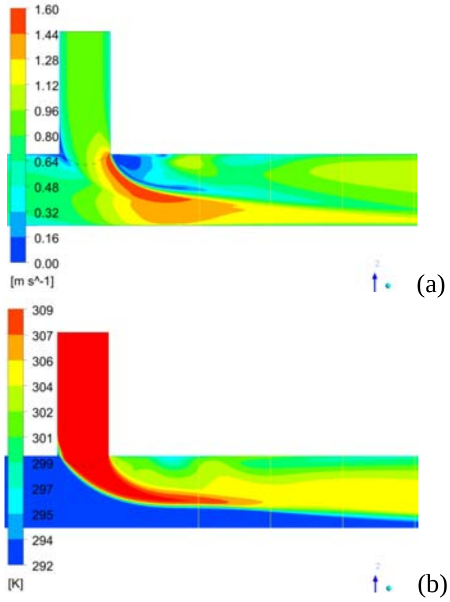

Fig. 3. Flow and Thermal Field in the T-junction: (a) Velocity (b) Temperature

3.3. Comparison of Turbulence Models

The transient evolutions of the axial velocity (U) at the center position of x=3.6D for various turbulence models are plotted in Fig. 4. Both k-ε and SST turbulence models which are (U)RANS model, predict the velocity as a steady state value, not fluctuating one. SAS-SST predicts fluctuating velocity profile during initial time; however, velocity becomes one steady state value eventually.

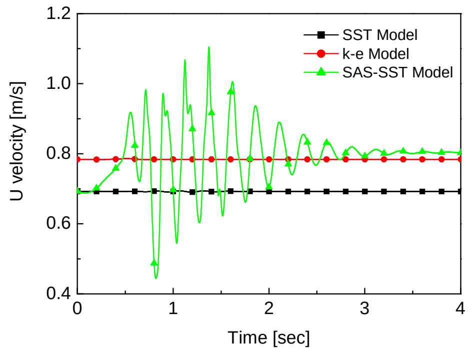

Fig. 4. Axial Velocity (U) for Various Turbulence Models

Figure 5 shows transient evolutions of temperature at the top and side position of cross-section of x=6D. Similar to velocity profile, steady state value for temperature is predicted by (U)RANS as well as SAS-SST turbulence model. Therefore, thermal striping and high frequency near-wall temperature fluctuations in T-junction are not predicted in this flow and thermal condition.

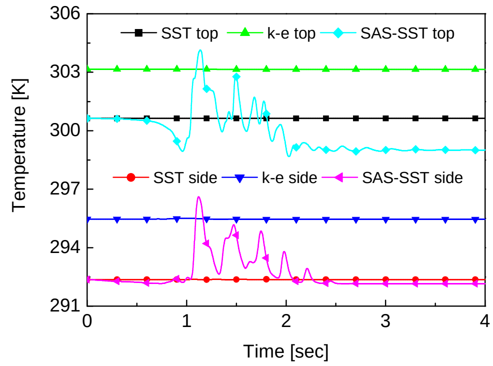

Fig. 5. Temperature at the Top and Side of Pipe for Various Turbulence Models

4. Conclusion

Transient CFD calculations for Vattenfall T-junction thermal mixing test are performed using (U)RANS turbulence models (k-ε, SST) as well as scale-resolving SAS-SST turbulence model. Expected high frequency near-wall temperature fluctuations are not predicted. LES turbulence model should be applied in this calculation in order to catch the high frequency fluctuation and complete the sensitivity study for turbulence models. After the release of experimental data which will be taken in May 2010, comprehensive comparison of CFD calculation results and experimental data will be performed.

REFERENCES

[1] OECD/NEA, OECD/NEA Sponsored CFD Benchmark Exercise: Thermal Fatigue in a T-Junction, Invitation Letter, April, 16, 2009.
[2] OECD/NEA, OECD/NEA-Vattenfall T-Junction Benchmark Specifications, July, 27, 2009.
[3] J. Westin et al., High-Cycle Thermal Fatigue in Mixing Tees, Large-Eddy Simulations Compared to a New Validation Experiment, Proceedings of ICONE 16, May 11-15, 2008, Orlando, Florida, USA.
[4] Y. Odemark et al., High-Cycle Thermal Fatigue in Mixing Tees: New Large-Eddy Simulations Validated Against New Data Obtained by PIV in the Vattenfall Experiment, Proceedings of ICONE 17, July 12-16, 2009, Brussels, Belgium.