Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Sensitivity of the Absorption Coefficient of Radiation Medium on the CFX Simulation of the CS28-2 Experiment

Hyoung Tae Kim, Bo Wook Rhee, Joo Hwan Park
Korea Atomic Energy Research Institute
150 Dukjin-Don, Yusong-Gu, Daejon 305-353, Korea
kht@kaeri.re.kr

1. Introduction

During a postulated LOCA without emergency cooling in CANDU reactors, a superheated steam becomes the only coolant available to the fuel channel. For this situation the radiation heat transfer is a dominant mode of the heat transfer. The radiation heat transfer analysis with assumptions of a non-participating medium completely enclosed with the diffuse, gray and opaque surfaces are practically used by most fuel channel codes such as CHAN-II and CATHENA [1].

In this study the assumption of the non-participating medium for the radiation heat transfer in the CANDU fuel channel analysis is assessed against the CS28-2 [2] experiment using the CFX-10 [3] code. For this purpose the sensitivity of the absorption coefficients of the steam on the radiation heat transfer is investigated.

2. Absorption Coefficient of the Steam

In the CS28-2 experiment the radiation heat transfer is dominant mode of the heat transfer. In order to correctly predict the radiation heat transfer, participating gases must also be considered in the radiation heat transfer model. Water vapour and carbon dioxide can absorb, emit, and scatter the radiation.

In the previous work the non-participating medium is assumed for the CFX simulation [4] of the CS28-2 experiment. However, the medium can be participating so that the absorbing medium can affect the radiation heat transfer.

The absorption coefficient is requested in units of 1/length. Along with the scattering coefficient, it describes the change in radiation intensity per unit length along the path through the fluid medium. Absorption coefficients can be computed using tables of emissivity for CO_2 and H_2O, which are generally available in textbooks on radiation heat transfer.

For the evaluation of total intensity or heat flux divergence, the absorption coefficient, known as the Plank-mean absorption coefficient [5] can be found in the Fig. 1.

For simplicity, a gray and a diffuse model was used with a fixed absorption coefficient for the participating gases in the present simulation. Therefore, the absorption coefficients used for steam and CO_2 during the steady state condition of the CS28-2 experiment are 0.07 cm^{-1} (1000 K) and 0.38 cm^{-1} (500 K), respectively.

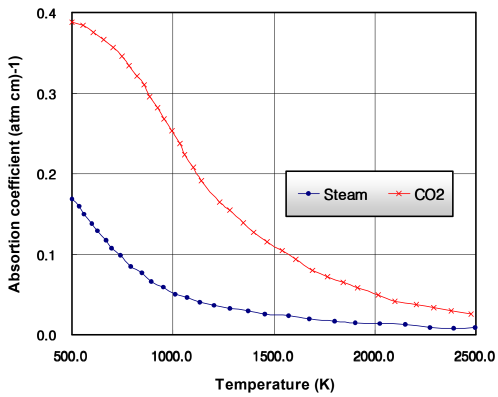

Figure 1 Schematic diagram of test section

3. CFX-10 Modeling for the CS28-2 Experiment

The fluid domains consist of the super-heated steam in the pressure tube and the CO_2 gas in the annulus between the pressure tube and Calandria tube. The solid domains consist of three heater rod walls (including graphite, Al_2O_3, and Zircaloy domains), the pressure tube wall, and the Calandria wall. The CFX simulation is performed by a single 3.0 GHz Intel Pentium 4 processor with a Window XP operation system.

Figure 2 shows the results of the grid generation with a refined mesh density near the wall boundaries. The number of the elements used is 764,901 and the number of the nodes is 1,014,888. If the number of the nodes is increased, it reaches the 2 GB memory limit that many users face when running large models on Windows.

The modeling of a pool surrounding the Calandria tube is simplified by using the temperature boundary condition (40℃) on the outer surface of the Calandria tube.

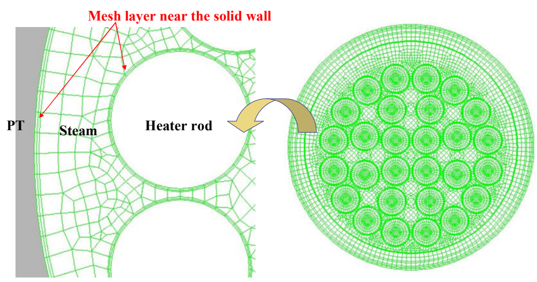

Figure 2 Mesh generation of the CS28-2 test section

4. Sensitivity of the Absorption Coefficient

For the sensitivity study of the absorption coefficient on the radiation heat transfer, the variation of the absorption coefficients for steam are 0.0 cm-1 (non-participating), 0.01 cm^{-1}, 0.07 cm^{-1} (steady state of the CS28-2), and 0.15 cm^{-1}. The absorption coefficient of the CO_2 is assumed to be 0.01 cm^{-1} (the default value for CFX-10 input) for these 4 cases.

5. CFX-10 Simulation Results

The steady state results for the CS28-2 are compared with the CFX-10 simulations for the various absorption coefficients of the steam. These comparisons are shown from Figs. 3 to 6.

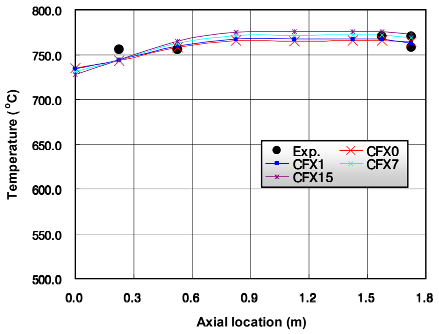

Figure 3 Axial temperature profile for the inner ring

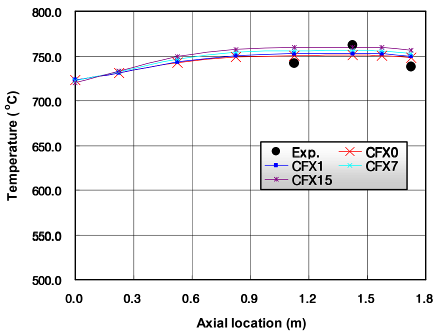

Figure 4 Axial temperature profile for the middle ring

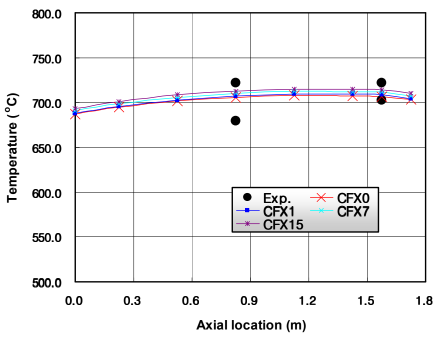

Figure 5 Axial temperature profile for the outer ring

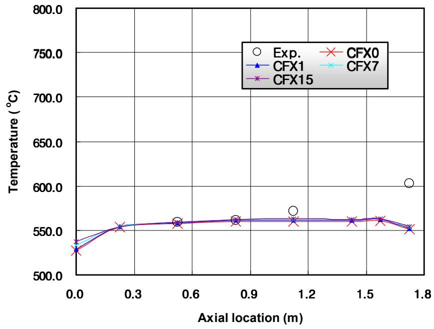

Figure 6 Axial temperature profile for the pressure tube

6. Conclusions

From the simulation of CS28-2 using the CFX-10 code, the following results are obtained.

- The predictions of the FES temperatures of the inner, middle and outer rings at different axial locations agreed well with the measured data to within 20 ℃, which is less than the uncertainty of the temperature measurements.
- A reasonable agreement between the predictions and the measurements of the pressure tube temperatures is obtained, except that the pressure tube temperature is under-estimated by 50 ℃ near the exit to the test section.
- The differences of the temperature predictions for the FES and the pressure tube with various absorption coefficients of steam are within 10 ℃, which is less than the uncertainty of the temperature measurements.

Further works are required for the sensitivity study of the absorption coefficient of CO_2 on the CS28-2 simulation.

REFERENCES

[1] T.G. Beuthe, and B.N. Hanna (editors), “CATHENA MOD-3.5c/Rev 0 Theoretical Manual”, CANDU Owners Group Report, COG-99-007, 1999.

[2] M.H. Bayoumi and W.C. Muir, “Post-Test Simulation and Analysis of the Second Full Scale CHAN 28-Element Experiment (Validation of CHAN-II (MOD6) against Experiments)”, 16th Annual Conference of Canadian Nuclear Society, Saskatoon, SK, Canada, 4-7 Jun 1995.

[3] “ANSYS ICEM CFD, Release 10.0: Tutorial Manual”, ANSYS, Inc., Canonsburg 2005.

[4] Hyoung Tae Kim, Bo Wook Rhee, and Joo Hwan Park, “CFX-5.7 Simulation of Thermal-Chemical Experiments for a CANDU Fuel Channel”, Proc. of KNS Busan Oct. 2005.

[5] Michael F. Modest, “Radiative Heat Transfer”, p.370, Int. Edition, McGraw-Hill, Inc. 1993.