A Study on the Thermal Radiation Heat Transfer in the CO_2 Annulus of CANDU-6 Fuel Channel under Post-Blowdown Phase of LBLOCA.

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1. Introduction

During the post-blowdown phase of a postulated Loss of Coolant Accident (LOCA) with impaired Emergency Core Cooling (ECC) in CANDU reactors, either saturated or superheated steam is considered to be the only coolant available in the fuel channel. In this condition the dominant path of removing the decay heat is considered to be the discharge via radiation heat transfer from the fuel elements to the huge moderator across the pressure tube and calandria tube[1]. As too high temperature of the fuel may initiate the auto-catalytic exothermic zircaloy-steam metal water reaction and, if progressed to worse situation, the breakdown of the mechanical integrity of the fuel sheath may cause collapse of the fuel bundle in the fuel channel, the confirmation of the adequate cooling capability of this heat transfer mechanism has been of great concern to the CANDU-6 safety analysis[2]. Recently in KAERI there has been a research for developing a new CANDU fuel channel safety analysis code system where the CHAN-II code is to be replaced by CATHENA for the post-blowdown phase analysis of the CANDU-6 fuel channel under LBLOCA w/o ECC. For the validation of this new CATHENA model a validation has been under way, and one of them is the validation against a high-temperature thermal-chemical experiment called CS28-1[1]. As quite a comprehensive experimental data available, this test was intensively studied and simulated using CATHENA code as well as 3D CFD code, CFX, equipped with various radiation models of popularity.

Three questions among many difficult challenges of this work were: (1) Why do the measured fuel temperatures of all the fuel rings show flat axial profile while the coolant shows increasing temperature axially. (2) How to justify the basic assumption of CATHENA radiation model, transparent medium assumption of the steam coolant for this experiment, and (3) Why neither codes fails to predict the measured pressure tube temperatures by a significant amount which cannot be explained?

The detail description of the CS28-1 experiment is well described in other literatures[1,2] and thus will be omitted here.

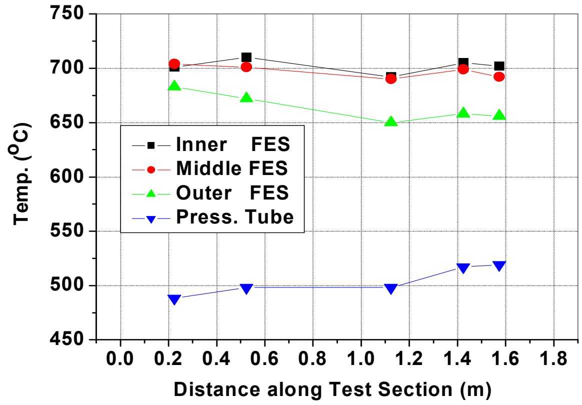

Fig. 1. Inner, Middle and Outer Ring FES and the PT temperatures along the axial direction [2]

2. Radiation Heat Transfer Model

In CATHENA, the radiation model calculates the heat exchange due to a thermal radiation among the solid component models; between the FES facing each other, between the FES and the pressure tube, and also between the pressure tube and the calandria tube. The view factor matrix is generated separately by using the utility program MATRIX. An emissivity of 0.8 (based on ZrO_2) is used for the fuel sheaths and the inside/outside surfaces of the pressure tube and 0.34 for the inside surface of the calandria tube. A detailed view factor matrix between the pressure tube and each of the 28 FES is generated first, and then converted to the contracted view factor matrix file which is consistent with the solid component models. In CFX 5-7 code[3], a direct coupling of mass- and momentum equations and thermal radiation equation is solved with several radiation modeling options: Rosseland model, the P-1 model, the discrete transfer model and the Monte Carlo model. For the current validation study, the discrete transfer model is chosen after cross checking against the Monte Carlo model.

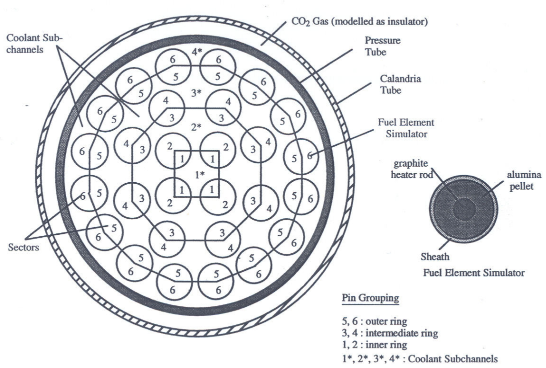

Fig. 2. CATHENA Solid Structure Model and Subchannel Model for CS28-1 Experiment

3. Computer Simulation Results and Discusiion

The dilemma was that even after accounting all the available models of CATHENA and CFX codes for the heat transfer calculation between the pressure tube and the calandria tube, there still remains a significant discrepancy between the measured pressure tube temperatures and those predicted by both codes[4]. Thus for CATHENA modeling it was decided to introduce a multiplying correction factor to the CO_2 conductivity necessary to match the measured pressure tube temperature, though the actual reason for enhanced heat transfer rate cannot be found[3]. However in the case of CFX, there is no room for adjustment and most recent founding is the possibility of the strong radiation absorption by the CO_2 gas in the PT/CT annulus and consequent convective heat transfer to the cold calandria tube[4]. Though even with this new improvement there exists about 50 °C overestimation of the pressure tube temperature along the test section.

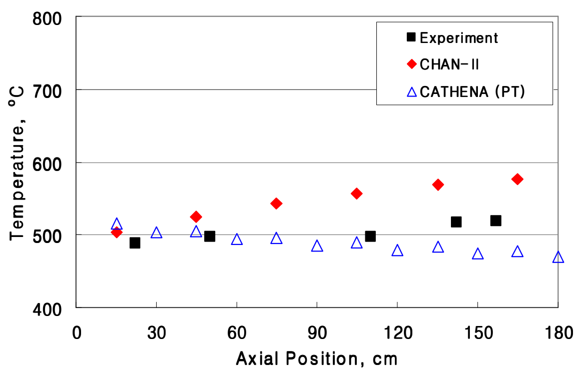

Fig. 3. Pressure Tube temperature along the axial direction after CO_2 conductivity adjustment.[2]

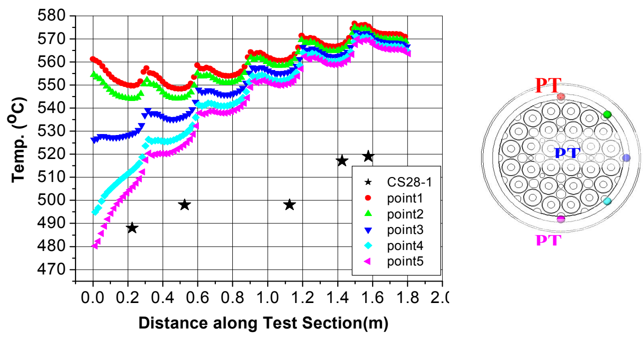

Fig. 4. Comparison of Test Data and CFD Results [4]

4. Conclusion

In the case of CATHENA simulation, once the pressure tube temperature is adjusted to be predicted correctly by the CATHENA model, all the remaining temperatures of the inner ring, middle ring and outer ring temperatures can also be predicted quite satisfactorily, say to within an accuracy range of ±20°C, which proves the robustness of the CATHENA radiation model between FES and pressure tube. In the case of CFX analysis for CS28-1, the results show that there remain a consistent systematic discrepancy between the code predictions and experiment measurement, Further in-depth study on the radiation and convective heat transfer phenomena in the narrow CO_2 gas gap is necessary to resolve the existing problem.

REFERENCES

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