

CFX-5.7 Simulation of Thermal-Chemical Experiments for a CANDU Fuel Channel

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1. Introduction

An experimental program, the CHAN thermal Chemical Experimental Program [1], has been performed by AECL in Canada for validation of computer codes such as CHAN-II and CATHENA. These codes are capable of predicting the thermal-chemical response of CANDU fuel channels during a postulated Loss-of-Coolant Accident (LOCA) without Emergency Core Cooling System (ECCS). This program consists of several series of experiments: a single fuel element simulator (FES), 7-element, and 28-element tests.

CS28-2, one of 28-element tests, has 3-dimensional effects due to eccentric configuration of test section. The Computational Fluid Dynamic (CFD) code, CFX 5.7 is used to simulate the CS28-2 test at this study.

2. Overview of CS28-2 Experiment

2.1 Test Apparatus

The test apparatus is shown in Fig. 1. The test section consists of the electrically heated FES bundle, pressure tube, gap annulus, and Calandria tube. The Calandria tube is surrounded by an open tank of 40°C water. The FES bundle is consisted of three rings of FESs and eccentrically located inside the pressure tube. This eccentric configuration is prepared to understand the fuel channel behavior when the pressure tube is ballooned and most of the steam flow is bypassed through the upper part of the channel.

The superheated steam at 670°C is injected to the inlet of the test section with a mass flow of 15 g/sec. The CO₂ gas flow in the annulus gap is 1.6 SLPM.

During the experiment, the electrically heated FESs are cooled by steam convection, conduction, and thermal radiation radially from FESs to the pressure tube and from the pressure tube to Calandria tube.

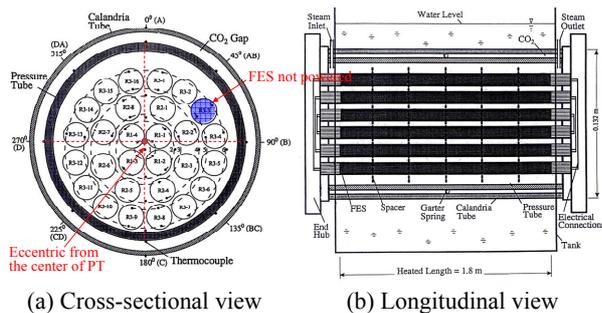


Figure 1 Schematic diagram of test section

2.2 Main Test Results

The power history curve of the FES bundle is shown in Fig. 2. The individual power is supplied to the outer, middle, and inner rings. The temperatures measured at FES and pressure tube are plotted in Fig. 3.

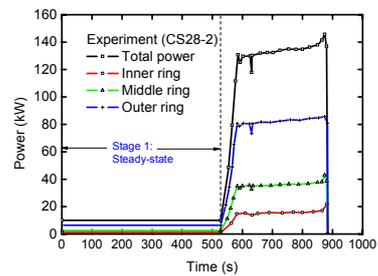


Figure 2 FES power transient

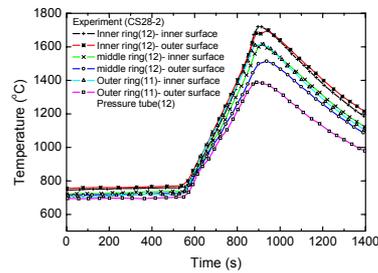


Figure 3 FES and pressure tube temperatures

3. CFX Modeling of CS28-2

3.1 Mesh Generation

The grid of CS28-2 test section is generated using the ICEM CFD [3] software. Figure 4 shows the results of grid generation and the mesh layers near the solid walls.

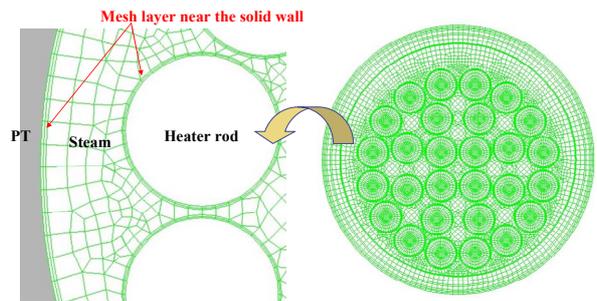


Figure 4 Mesh generation of CS28-2 test section

3.2 Material Properties

The materials used in the domain setting are graphite, Al_2O_3 , Zircaloy, steam, and CO_2 . Zircaloy is used for FES sheath, pressure tube, and Calandria tube. These properties are the same as those used in CATHENA code [4].

3.3 Boundary Conditions

The modeling of pool surrounding the Calandria tube is simplified using the temperature boundary condition ($40^\circ C$) on the outer surface of the Calandria tube. The steam injection flow is modeled by mass flow rate boundary condition at the inlet on the interface between steam and pressure tube domains. The FES power is modeled by an energy source within a solid sub-domain.

4. Discussion of Simulation Results

The present simulation of CS28-2 is performed only for steady-state conditions in this study.

Figure 5 shows the stream lines of steam flow in the test section. It is confirmed that steam is injected and vented through upper sides of test section.

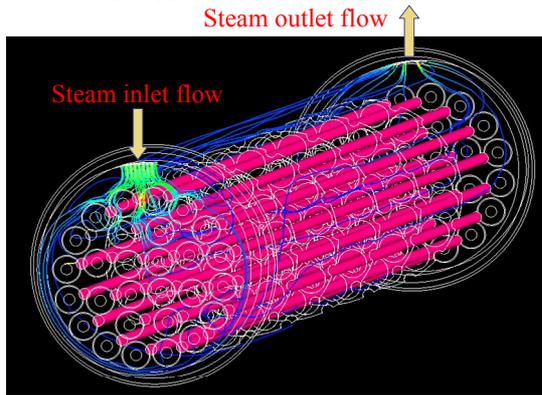


Figure 5 Stream lines of steam flow in the test section

FES temperatures are calculated along the axial direction of the test section as shown in Fig. 6. The predictions of FES temperature are higher than the experimental results. Considering the validation work for radiation heat transfer of CFX-5.7 [5], this discrepancy may come from inaccurate prediction of convection heat transfer or unknown heat loss in the experiment. The temperature drops at both ends of the heated section are due to the heat loss to the unheated zone at both ends

Figure 7 shows the radial temperature distribution between pressure tube and Calandria tube including the CO_2 gap. The temperature prediction of the pressure tube is well agreed with the measured value, $600^\circ C$ as shown in Fig. 7. The linear temperature gradient at CO_2 gap comes from the conduction heat transfer and its heat transfer rate is estimated as $7000.0 W/m^2$ using the CO_2 conductivity ($0.04 W/m\cdot^\circ C$) at average temperature of $320^\circ C$. This value is much higher than the natural convection heat transfer rate; $3017.2 W/m^2$, calculated by the correlation of Raithby and Hollands [6].

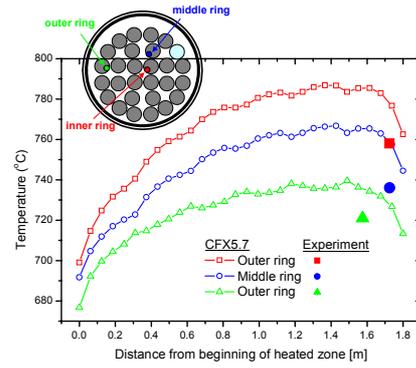


Figure 6 Axial temperature distributions of FESs

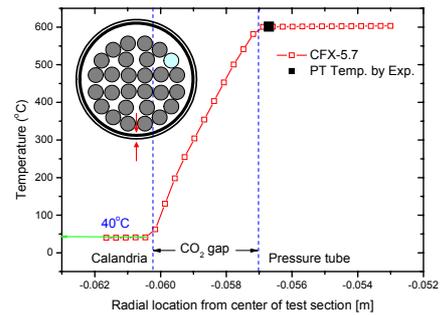


Figure 7 Radial temperature distribution in the annulus gap (at axial location of 1.725 m)

5. Conclusions

From the simulation of CS28-2 using CFX-5.7 code, the following results are obtained.

- CFX-5.7 predictions of FES temperature are higher than the experimental measurements by $10\sim 20^\circ C$.
- The prediction of the pressure tube temperature is well agreed with the measured data at exit region.
- FES temperature drops at both ends of the heated section in CFX-5.7 simulation, which is attributed to heat loss to unheated zone.
- Gap conductance and thermal radiation are dominant heat transfer modes in the annulus gap of CS28-2.

Further works are required for investigation of discrepancy of code prediction and transient simulation.

REFERENCES

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