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Multiphysical Simulation of PT-CT Contact with Outer Boundary Condition

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1. Introduction

One of the important design features of a CANDU reactor (a pressurize heavy water reactor) is the use of moderator as a heat sink during some postulated accidents such as a large break Loss Of Coolant Accident (LOCA). If the pressure tube is sufficiently hot while the channel pressure is still relatively high, the pressure tube may radially deform and would fully contact with its surrounding calandria tube (pressure tube/calandria tube ballooning contact).

International Atomic Energy Agency (IAEA) has launched the International Collaborative Standard Problem (ICSP) to provide a new contact boiling experimental data to assess the subcooling requirements for a heated pressure tube, plastically deforming into contact with the calandria tube during a postulated large break LOCA condition. We participated in 1st Workshop of IAEA ICSP on “HWR Moderator Subcooling Requirements to Demonstrate Backup Heat Sink Capabilities of Moderator during Accidents” (Ottawa, November 2012; Fig. 1) [1].

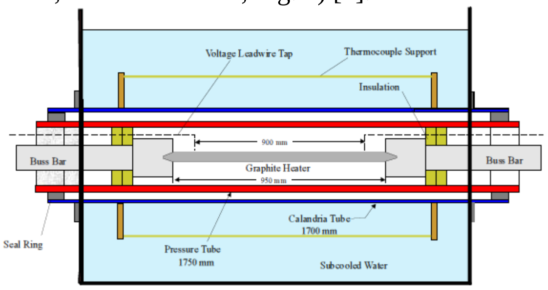


Fig. 1. Experimental Setup [1]

The present study is about preliminary calculation results for these ICSP activity works, where the COMSOL Multiphysics code [2] is used to simulate plastic deformation of a pressure tube as a result of the interaction of stress and temperature. It is shown that the thermal stress model of COMSOL is compatible to simulate the multiple heat transfers (including the radiation heat transfer and heat conduction) and stress strain in the simplified 2-D problem. The benchmark test result for radiation heat transfer is in good agreement with the analytical solution for the concentric configuration of PT(pressure tube) and CT(calandria tube).

In this paper, the authors did an open computation of these multi-physical phenomena by changing the outer boundary condition of CT according to the experimental result of ICSP.

2. Methods and Results

In this section, the numerical method and some selected result is presented. The experimental setup [1] and its simplified schematic are given in Fig. 1.

2.1 Experimental Method

Strain gauges and thermocouples are attached on the PT and CT in the radial direction of four points per each axial station. The heat source in Fig. 1 is 150 kW at the graphite heater centered on the apparatus. The unsteady signal of measurement is transduced to the multi-channel analyzer.

2.2 Numerical Model

The numerical model is given in detail in Ref. [2]. Since the original strain model of COMSOL only considers an elastic deformation with thermal expansion coefficient, the pressure tube/calandria tube contact cannot be predicted in the ICSP problem. Therefore, the plastic deformation model by the Shewfelt and Godin [2], widely used in the CANDU fuel channel analysis, is implemented to the strain equation of COMSOL.

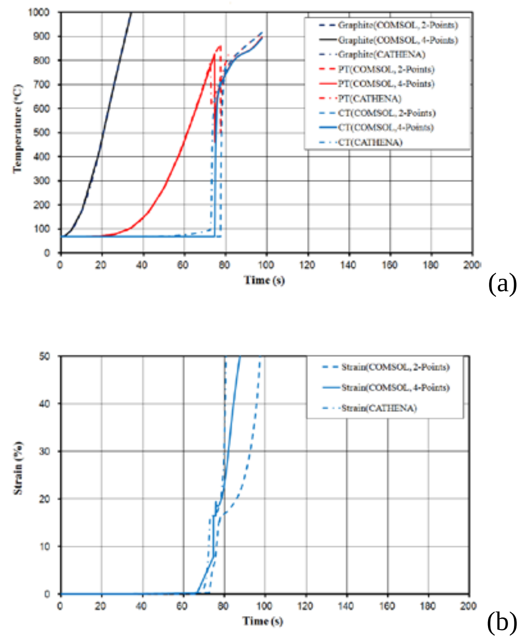


Fig. 2. Result of Computation for the Constant Temperature Boundary Condition: (a) Temperature, (b) Strain [2]

Table I: Problem Description

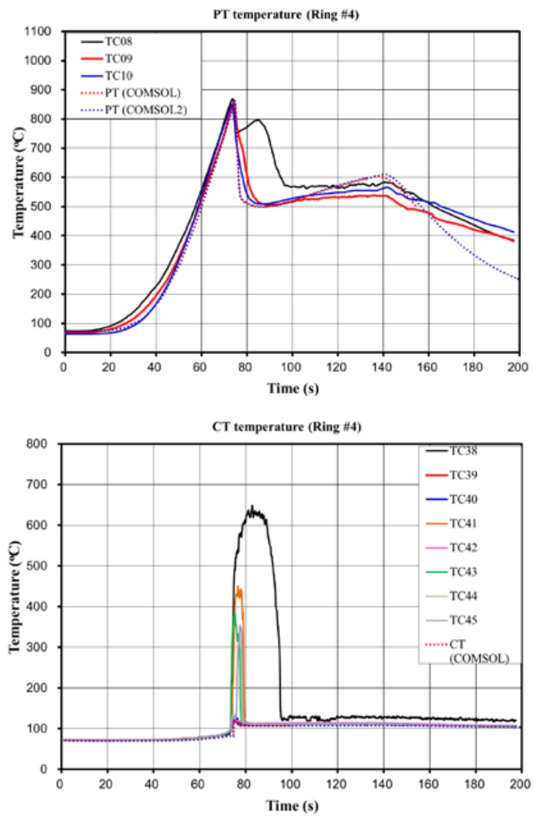
T(^oC)	Flow regime	Model
<100	Liquid free convection	Churchill & Chu
<125	Nucleate boiling	Rohsenow
=125	CHF(critical heat flux)	Zuber & Griffth
<289	Transition boiling	Bjornard & Griffth
>289	Film boiling	Bromley

The nonlinear integration of strain rate is numerically modeled with Gaussian quadrature method, and the result shows a good agreement with the CATHENA code result as increasing the accuracy of numerical technique [3]: see Fig. 2.

2.3 Outer Boundary Condition

The boundary condition at the outer surface of CT is specified such as Table I. The flow regime is varied from the natural convection to the film boiling according to the pool temperature of coolant.

One of typical result of this open computation is shown in Fig. 3. The temperature inside PT shows a good agreement with experimental result while that out of CT does not correctly predict the peak temperature. The outer boundary condition does not work near the CHF in Table I. The strain also shows a poor agreement with experiment. Therefore, the exact heat flux data is required at the outer surface of CT.



(a)

(b)

Fig. 3. Temperature under the Changed Outer Boundary Condition: (a) Inside PT, (b) Outside CT

3. Conclusions

A series of simulation has been done based on the benchmark test proposed by IAEA/ICSP. The unsteady multi-physics was treated some numerical models with COMSOL. The comparison with CATHENA code is verified as a good agreement as we increase the accuracy of numerical method, Gaussian quadrature.

The open computation for the validation of this numerical code is still on-going, and the temperature inside and outside the PT shows a very good agreement. However, the change of outer boundary condition at the interface between CT and coolant does not work well at the CHF flow regime, so the present models are not good for this experiment. The exact heat flux at the outer boundary of CT is required for the future work.

REFERENCES

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