Numerical Modeling of Power Reactors' Fuel Bundles

R. Schmidt[1,2], T. Yousefi[2], B. Farahbahksh[2] and M.Z. Saghir[2]
[1]University of Louisiana at Lafayette, Dept of Mechanical Engineering, Lafayette, LA, USA
[2] Ryerson University, Dept of Mechanical and Industrial Engineering, Toronto, ON, Canada

Introduction: CANDU (CANada Deuterium Uraniam) reactors are currently using heavy water as its pressurized coolant. The purpose of this study was to create a valid COMSOL model for one configuration of fuel rod bundles. The thermal behavior of the model for different Reynolds numbers has been investigated and the average heat transfer coefficients for each case have been plotted. Figures 1 and 2 show different configurations of CANDU fuel rod bundles.

Figure 1:
Example of Bruce 37 Element

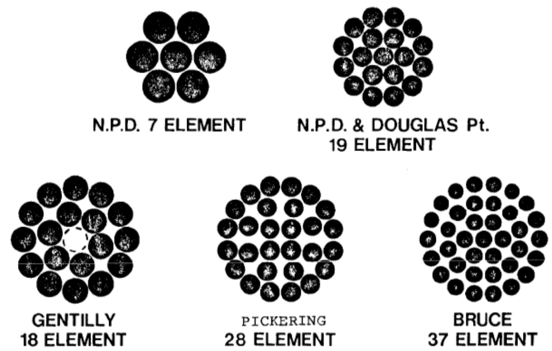

Figure 2:
Different Configurations of CANDU Fuel Bundles

Computational Methods: Using the heat transfer module in COMSOL Multiphysics, the governing equations including continuity, momentum, and energy equations and their appropriate boundary condition are as follow:

$$\nabla \cdot \mathbf{v} = 0 \qquad (1)$$

$$\rho \frac{D\mathbf{v}}{Dt} = \rho \mathrm{g} - \nabla p + \mu \Delta \mathbf{v}, \qquad (2)$$

$$\rho\, Cp\, V \cdot \nabla^2 T + \mu\phi + \dot{q} \qquad (3)$$

The boundary condition for inlet and outlet velocities are 0.0196 m/s (Case 1), 0.0222 m/s (Case 2), 0.02461 m/s (Case 3), and 0.03004 m/s (Case 4). The inlet and outlet velocities are equal. The boundary condition for rods is constant heat flux and the shell is considered as insulation.

The geometry of the model is based on the specifications provided by CANDU 6 Technical Summary [1]. The specific material of the rods as well as the fluid was chosen off of this source as well. Figure 3 shows the geometry of the rod bundle of 7 considered for this investigation.

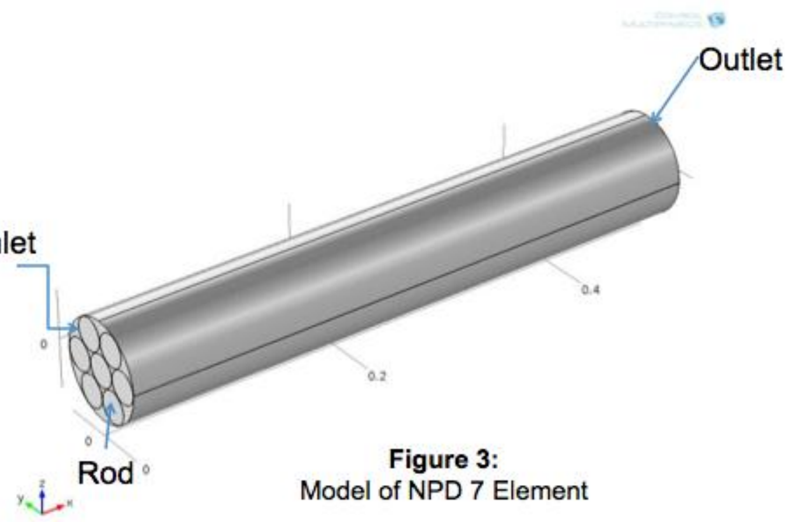

Figure 3:
Model of NPD 7 Element

Results: Figures 4 shows the variation of average heat transfer coefficient for center rod and bottom left rod. As it can be seen by moving from the inlet toward the outlet, the convective heat transfer coefficient for the bottom rod is decreased due to the increasing of boundary layer thickness. However, for center rod this variation is very small. This can be described, by considering the effect of other rods' boundary layer on this rod and narrowing the flow passage for center rod along the flow direction. Having a narrow passage, the flow around the center rod acts like a flow inside closed tube, which the heat transfer coefficient in it is approximately constant.

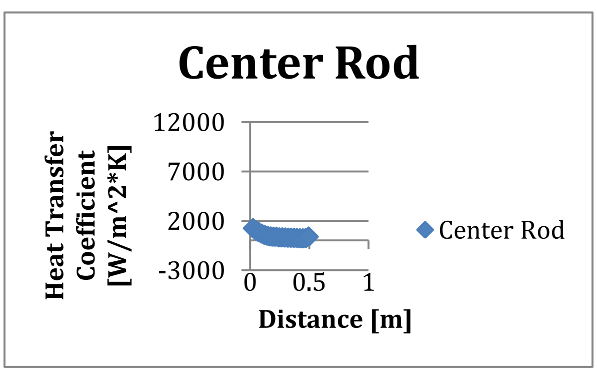

Figure 4
Center Rod Heat Transfer Coefficient

Figure 5 shows the expected results of the average heat transfer convective coefficient for all the rods for different cases in table 1. Figure 6 shows the expected gradual increase in fluid temperature.

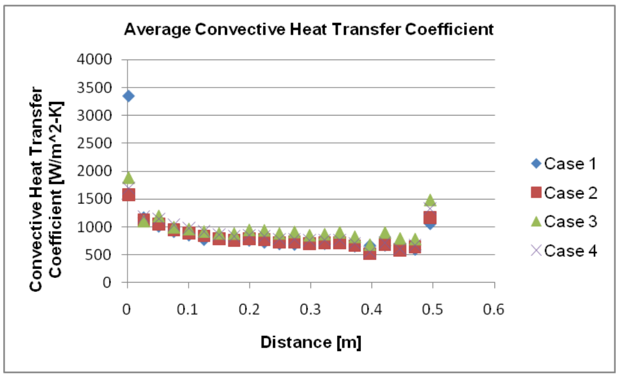

Figure 5
Variation of average heat transfer coefficient for tube bundle for different cases of Table 1

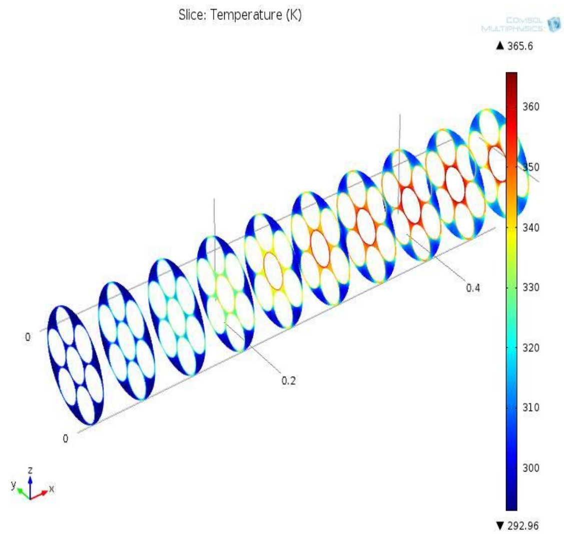

Figure 6
Temperature Slice of Case 1

References:

[1] CANDU 6 Technical Summary, prepared by CANDU 6 Program Team, Reactor Development Business Unit, May 2005.