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A study on the effect of the Radiation on the CANDU Fuel Channel Thermalhydraulics in a Stratified Two-Phase Flow Condition

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1. Introduction

In some postulated Loss-of-Coolant accidents (LOCAs), coolant flow in the fuel channels of a CANDU reactor may become stratified. Steam generated will flow to the top of the fuel channel. Experimentally this phenomenon has been observed in the CWIT experiments[1]. Through radiation and steam convection, the exposed part of the pressure tube will heat up. As the coolant level drops, the pressure tube gets hotter and hotter at the top while it remains below or at the saturation temperature below the liquid level. To test the capability of MARS code for this condition, a CANDU fuel channel model with the radiation model treating every fuel pin individually was developed and tested. The result is encouraging and for the fuel cladding temperature around 780^{o}C the effect of radiation model on the fuel temperature was found minimal.

2. Radiation Heat Transfer Model

In MARS[2], the radiation model calculates the heat exchange due to a thermal radiation among the solid component models such as those between the FES facing each other, between the FES and the pressure tube, and also between the pressure tube and the calandria tube. Here for the simplicity, the interaction between the pressure tube and calandria tube is neglected. In MARS, the radiation heat transfer absorbed in the fluid cannot be considered and thus neglected, and the validity of this approximation needs to be confirmed for each application like in CATHENA code[3]. The view factors are 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 surface of the pressure tube. In this study the thermal boundary condition imposed are those of the inlet flow enthalpies of each phase, and the pressure tube outside temperature.The 37 fuel rods are grouped to 2 groups. One exposed to the steam above the water level, and the other submerged in the water. Here the convective heat transfer mode are different, and the radiation calculation model is applied to all the fuel rods irrespective of whether they are above or below the water level. Axially the whole fuel channel of about 6 m are divided into 12 segments both hydraulically and heat structure-wise. The schematic configuration of the fuel bundle and the pressure tube, and calandria tube is depicted in the Figure 1.

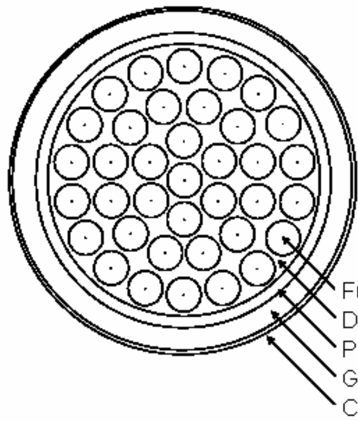


Fig. 1. MARS Solid Structure Model and Radiation Model for Standard 37-Pin Fuel

3. Surface-to-Surface Radiation Model

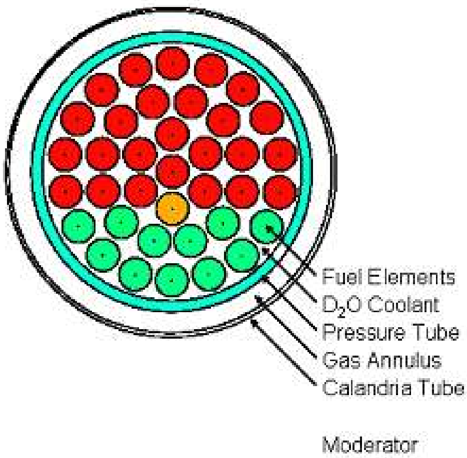
The computation method is a lumped-system approximation for gray diffuse surfaces contained in an enclosure. The assumptions of this method are that:

- ○ The fluid in the enclosure neither emits nor absorbs radiatnt thermal energy.
- ○ Reflectance from a surface is neither a function of incident nor reflected direction nor of radiation frequency.
- ○ Temperature, reflectance, and radiosity are constant over each surface.

The view factors from each surface to all other surfaces must sum to 1. Also, to conserve energy, the area times view factor for each surface i to any other surface j must equal the area of j times the view factor from j to i. The view factor was calculated using MATRIX code [4] which was validated and widely used for CATHENA application.

4. MARS Simulation Results and Discussion

A simple test problem is formulated and tested. Initially the channel was filled with a saturated water at 10.69 MPa and a saturated two-phase mixture of flowing quality of $1.566x10^{-2}$ was injected to the channel at the mass flux of 74.7 kg/(sec.m^2) and at the same time the total heat of 500kW was applied uniformly to the 37 fuel rod strings with chopped cosine axial profile and two phase was formed gradually along the axial direction. The radiation heat transfer model was utilized to simulate the two-phase heat transfer among the fuel rods and pressure tube at this stratified flow condition. The view factors among these thermal structures were calculated separately using the MATRIX code developed for CATHENA code. The thermal boundary conditions for this fuel channel are inlet flow and enthalpy at a given pressure, and the fixed temperature of the pressure tube outside, which is 588 ^oC. A typical result at the 8^{th} axial bundle location from the inlet out of 12 bundles in a channel is depicted in Fig. 2.



The incorporation of the full ledged 37 element CANDU standard fuel seems satisfactory, and further detailed modeling of the circumferential variation of the fuel rods as well as the pressure tube temperatures need to be developed for the realistic validation of this model against the available experimental data.

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