Modeling Research Reactor Fuel Plate Hotspots with the Thin Layer and Thermal Contact Feature in COMSOL Multiphysics® Software

M. J. Richards[1], A. E. Ruggles[2], J. D. Freels[3]

[1]Bredesen Center for Interdisciplinary Research and Graduate Education, University of Tennessee, Knoxville, TN, USA
[2]Department of Nuclear Engineering, University of Tennessee, Knoxville, TN, USA
[3]Research Reactors Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA

Abstract

Nuclear research reactors offer unique capabilities that provide opportunities for material irradiation and neutron scattering not available in power reactors. The use of high enriched uranium (HEU) in some research reactors creates a nuclear material proliferation vulnerability. To help prevent proliferation of nuclear weapons while allowing the continued use of these reactors, efforts are underway to convert from HEU to low enriched uranium (LEU) fuel. Among the challenges with this conversion is the thermal-fluid performance of the fuel. Hotspots caused by fuel segregations (regions of the fuel with higher heat generation rates and lower thermal conductivity) and non-bonds (regions of very low thermal conductivity between the fuel and cladding) limit plate-fueled research reactor performance. Accurate modeling of hotspots is required for qualification of new LEU fuels as well as improved use of current HEU fuels.

The thin layer (TL) and thermal contact (TC) features in the Heat Transfer Module of COMSOL Multiphysics® software offer a new approach to modeling non-bonds. In this study, a simplified model of a fuel plate is developed (Figure 1). Functions are created to control the location, size, and conductivity of the non-bond. A number of cases are run (1) to observe how the inclusion of TL and TC features change the results of the model, (2) to compare the results of models with non-bonds created with TL, TC and by conventional FEA methods, and (3) to observe the effects of the inclusion of fuel segregations both independent of and coincident with non-bonds (Figure 2). Temperatures, conductive heat fluxes, and energy balances are reported for the simulated cases.

For models without a non-bond, both TC and TL experience an approximately 0.01% change to the energy balance when compared to the base model. The conductive heat flux along the TC and TL boundary are very similar to the base model, except for at the edges of the boundary where oscillations occur, and the TL and TC fluxes drop to 0. Introduction of a non-bond does not change the energy balance, though spikes and oscillations are observed along the non-bond boundary in both boundary and domain heat flux for TL and TC models that are not physical. Refining the mesh or increasing the element order reduces the severity of the spikes and can eliminate the oscillations (Figure 3). The

addition of a fuel segregation results in larger errors in energy balance, and more severe distortions in boundary and domain conductive heat flux. As with the non-bond alone, these distortions can be reduced or eliminated with a sufficiently fine mesh or increased element order.

Both TL and TC are similar in performance, but the thermal contact model offers flexibility that make it the more appealing option for non-bond modeling. Care must be exercised in mesh development to ensure flux spikes and oscillations within the TL and TC boundary layer features are at acceptable levels. Additionally, increasing the order of the elements helps to reduce the distortions near discontinuities or steep gradients within the boundary layers.

Figures used in the abstract

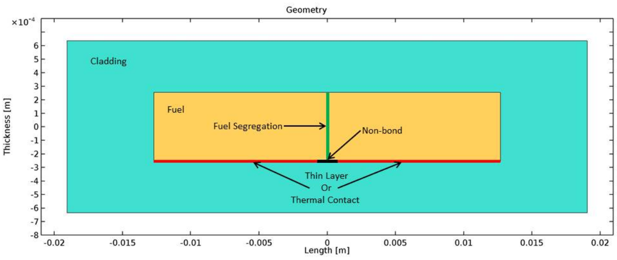

Figure 1: Simplified model of a fuel plate with a non-bond and fuel segregation.

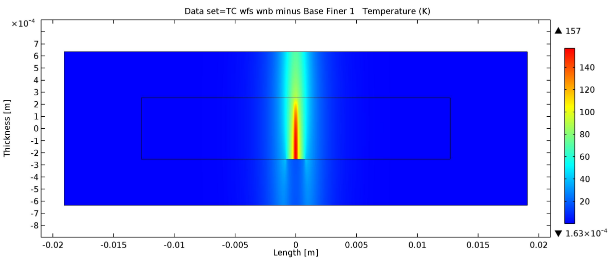

Figure 2: Increase in temperature caused by the presence of a fuel segregation and a TC non-bond.

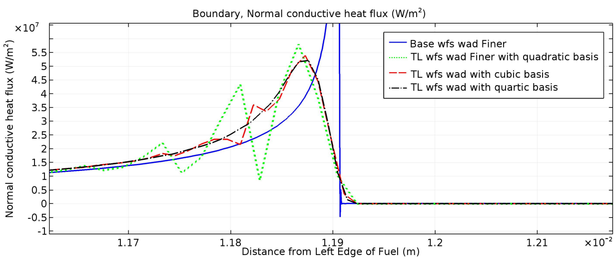

Figure 3: Effect of increased element order on distortions in boundary heat flux near non-bonds.