Simulating HFIR Core Thermal Hydraulics Using 3D-2D Model Coupling

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Abstract

Motivation:

The High Flux Isotope Reactor (HFIR) at Oak Ridge National Labs provides the highest neutron flux of any research reactor in the United States. The HFIR has operated for more than forty years using highly enriched uranium (HEU) as a fuel source. As part of an on-going effort by the National Nuclear Safety Administration to significantly reduce the amount of HEU across the globe, the United States has begun the process of converting its HEU-powered nuclear reactors to accommodate low-enriched uranium (LEU) as a safer alternative fuel source. As part of this on-going fuel conversion, computational simulations have come to play a key role in testing, validating, and discounting future fuel designs and reactor core alterations.

Introduction:

The HFIR core is a complex geometry consisting of 540 involute fuel plates arrayed in two concentric rings, as shown in Fig. 1. Using external CAD packages such as SolidWorks®, it has been possible to build an individual fuel plate, along with internal fuel geometry and surrounding coolant channel, and import the resultant assembly into COMSOL Multiphysics® for study. This approach yielded highly complex and detailed models capable of capturing the heat transfer interplay between the internal fuel meat, fuel plate, and external coolant flow. The model's complexity, however, is its limiting factor. A given model has on the order of 10 million degrees of freedom and requires valuable computing resources to simulate. Given these computational requirements, it is impossible to represent the entire reactor core using 540 of such detailed models. It is the intent of the full paper to follow to detail a simplified approximate model using 3D-to-2D model couplings to recreate the standard fuel plate model on a much more efficient scale.

Methodology:

Where the initial fuel plate model represented the entire assembly in three dimensions, the coupled model maintains the three dimensional fuel meat and plate while substituting the coolant with a two dimensional approximation, as shown in Fig. 2. By simplifying the coolant the model's degrees of freedom and memory requirements dropped by factors of 20 and 10, respectively.

The model works by passing surface temperatures from the concave and convex sides of the fuel plate to the coolant sidewalls. Channel width-averaged bulk temperature values are then passed back to the fuel plate surfaces via a convective boundary condition. The resultant coupled model allows for axial variations of coolant temperature. Preliminary results yielded a maximum fuel plate surface temperature of 385 K where the fully three-dimensional model yielded 393 K. The addition of "paneling," the process in which each side of the fuel plate is subdivided into multiple surfaces and then linked to its own coolant channel, will also be detailed. This concept is demonstrated graphically in Fig. 3.

Conclusion:

This simplified model will allow for the creation of the first-ever computer model of the entire reactor with each physical component represented explicitly. Such a model will make it possible to conduct flow blockage and fuel defect studies that have up to this point only been guessed at.

Figures used in the abstract

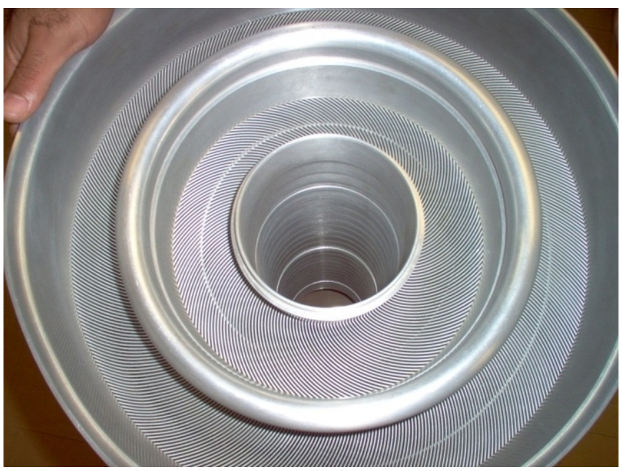

Figure 1: Top-down view of the HFIR core. The core's fuel plates are divided into an inner and outer elements, totaling 540 plates.

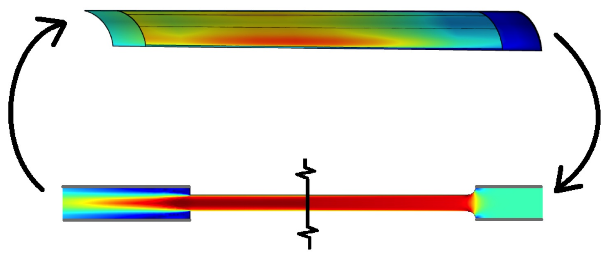

Figure 2: The approximate model consists of a three-dimensional fuel plate(top) and two-dimensional coolant channel(bottom). The color maps that both geometries are shown in are for temperature and velocity, respectively.

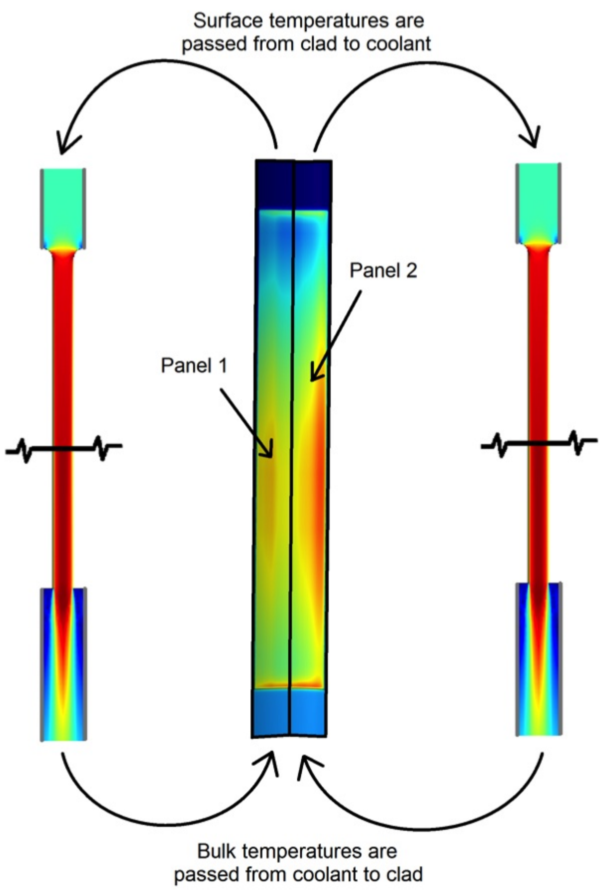

Figure 3: Basic two-panel configuration. The three-dimensional fuel plate geometry is unchanged internally. Each convective face is merely split into two surfaces and then linked to its own coolant channel allowing for slight variations in spanwise coolant temperature.