

Intermediate Heat Exchanger Dynamic Thermal Response Model

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Interim Report

This report presents an update on UCB progress in developing a comprehensive thermal and fluid dynamics model for the NGNP intermediate heat exchanger (IHX) and other compact heat exchangers. The thermal and hydraulic model uses an effective porous media (EPM) approach because the evaluation of the detailed flow, due to the prohibitive computational cost to model temperature and stress distributions in a typical compact heat exchanger with computational fluid dynamics (CFD) and finite element methods (FEM), at the resolution scale of the flow channels. The code development effort involving steady state and transient flow distribution and thermal response is nearing completion. Once completed, the temperature-distribution results will be transferred to a finite element analysis (FEA) code for mechanical stress analysis, using EPM methods developed earlier by UCB for global and local stress analysis [1]. These simulation tools will then allow the researcher to optimize the design to maximize thermal effectiveness while designing the IHX to resist creep and transient thermal stress.

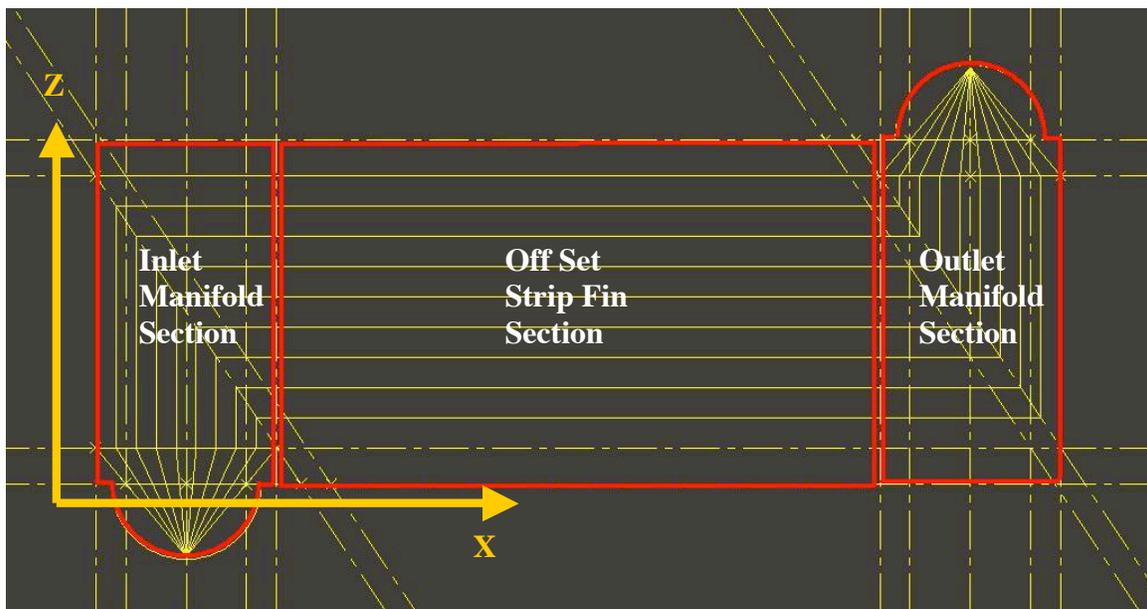


Fig. 1: Schematic of the IHX section for a LS plate

The IHX thermal and hydraulic model is built from 3 main sections, consistent with the design of a typical “Heatric” heat exchanger. The example studied here considers heat transfer from helium to a liquid salt, but helium-to-helium can also be modeled. In the direction of liquid salt (LS) flow, the first section is the inlet manifold, the second is the off set strip fin (OSF) section and the third is the outlet manifold section. These 3 sections can be observed below in a schematic of the IHX from the molten salt side, Figure 1.

Fluid dynamics as well as steady state and transient thermal models have been completed for each of the three phases in the OSF portion of the IHX (hot fluid, solid, and cold fluid). The analysis in this case uses fluids in counter flow but also calculates cross flow in each liquid phase. Preliminary work showing the transient temperature distribution in the solid is shown below for scenarios where the hot fluid pump shuts down. Should the liquid salt (hot fluid) pump trip, the transient thermal response from a steady state operating temperature distribution occurs over roughly 4 seconds, as shown in Figure 2.

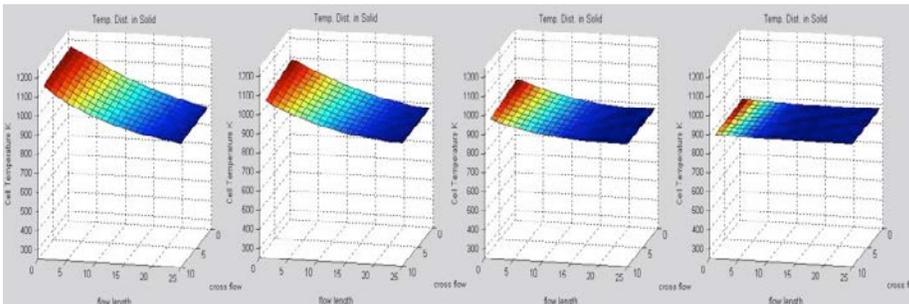


Fig. 2 Four second thermal transient in solid layer of HX after hot fluid pump trip

If the high pressure helium (cold fluid) pump trips, the transient thermal response from the same steady state operating temperature distribution occurs over roughly 5 seconds, this is shown in Figure 3. In this second case the slower hot molten salt can be seen affecting the temperature in the solid by advancing a well defined temperature front from left to right.

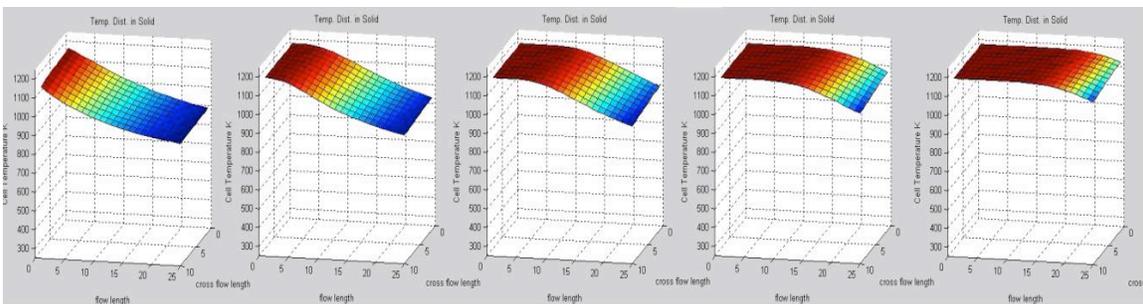


Fig. 3 Five second thermal transient in solid layer of HX after cold fluid pump trip

The LS inlet manifold is the most geometrically complex area of the IHX. The fluid dynamics model has just been completed for this section. In its current form the fluid dynamics model for the inlet manifold contains over 30 regions with different effective

permeabilities. Many of these sections lie in the diffuser and contain permeability fields where the permeability of each node is dependant on its coordinates. The computational model has been set up so that the flow resistance in each of the regions within the manifolds can be adjusted independently despite the fact that the permeability of each region is already based on geometrical features such as the channel density (number of flow paths per unit area) and channel orientation. This allows the researcher to modify the permeability manually until the pressure at the inlet to the OSF section is uniform in the z – direction (shown as vertical in Fig. 1). Lastly, the perfect symmetry between the inlet and outlet manifold geometry makes solving the fluid dynamics in the outlet manifold section a simple inversion of the code used in the inlet manifold section.

Obtaining a uniform pressure distribution at the entrance of the OSF section is critical for maximizing the heat exchanger’s effectiveness. A variation in the pressure means that the fluid velocity varies at the entrance to the OSF region and/or that the heat exchanger will experience cross flow in the OSF region. A pressure distribution for the MS plate side inlet manifold section can be seen below in Fig. 4.

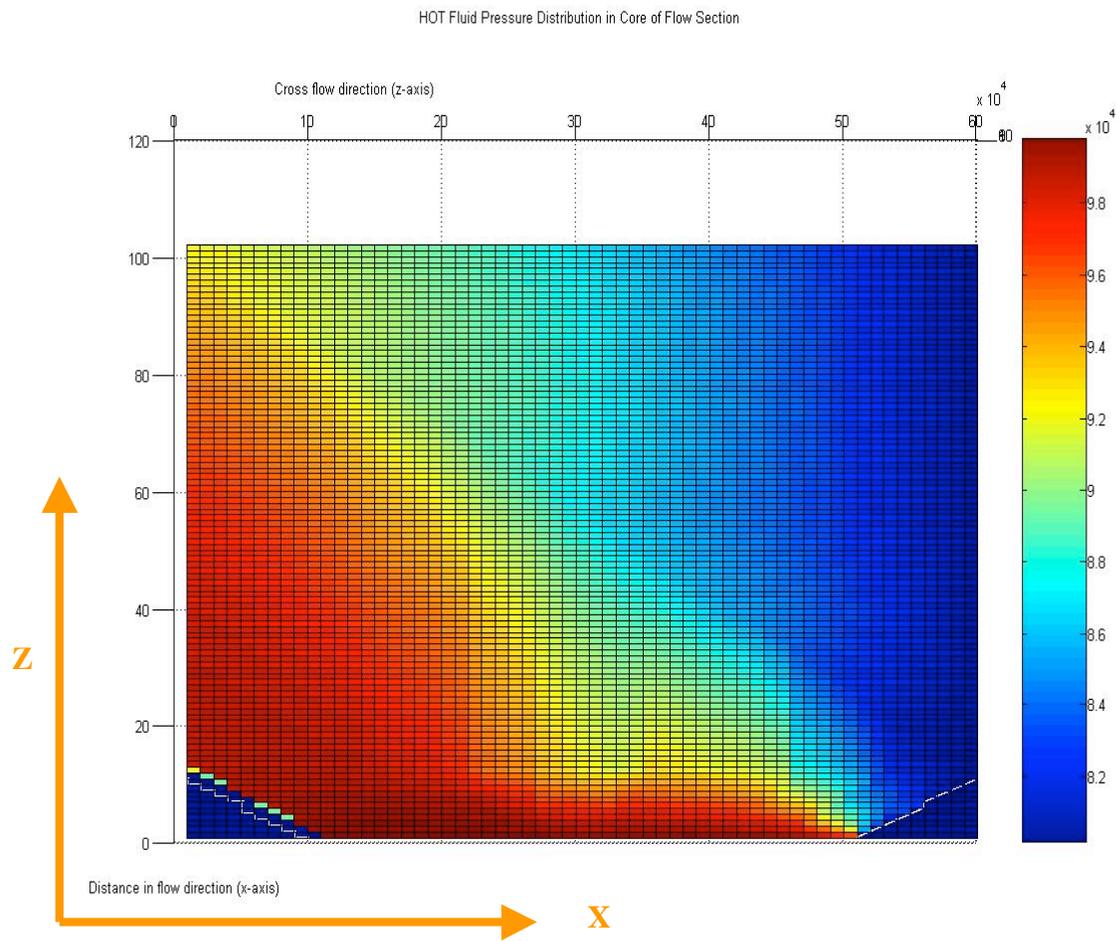


Fig. 4 One possible steady state pressure distribution for the MS inlet manifold [Pa]

Any flow maldistribution affects the effectiveness of the IHX negatively by reducing the effective area of the HX that contacts the fluid. This flow maldistribution can be caused by a multitude of factors such as fouling, manufacturing tolerances, channel closure due to creep or variations of fluid properties with temperature. Having the ability to adjust the permeability of the individual sections is an important analysis tool that allows the researcher to study the adjustment's effect on the flow field and further evaluate the sensitivity of the thermal effectiveness of the IHX. Figure 5 below shows the flow field corresponding to the pressure gradient seen for the inlet manifold depicted in Figure 4 above. Furthermore, the system geometry is also included in variable form in a CAD drawing so that any change in the dimensions of the IHX will update the critical system parameters used in the computational model for efficient design optimization.

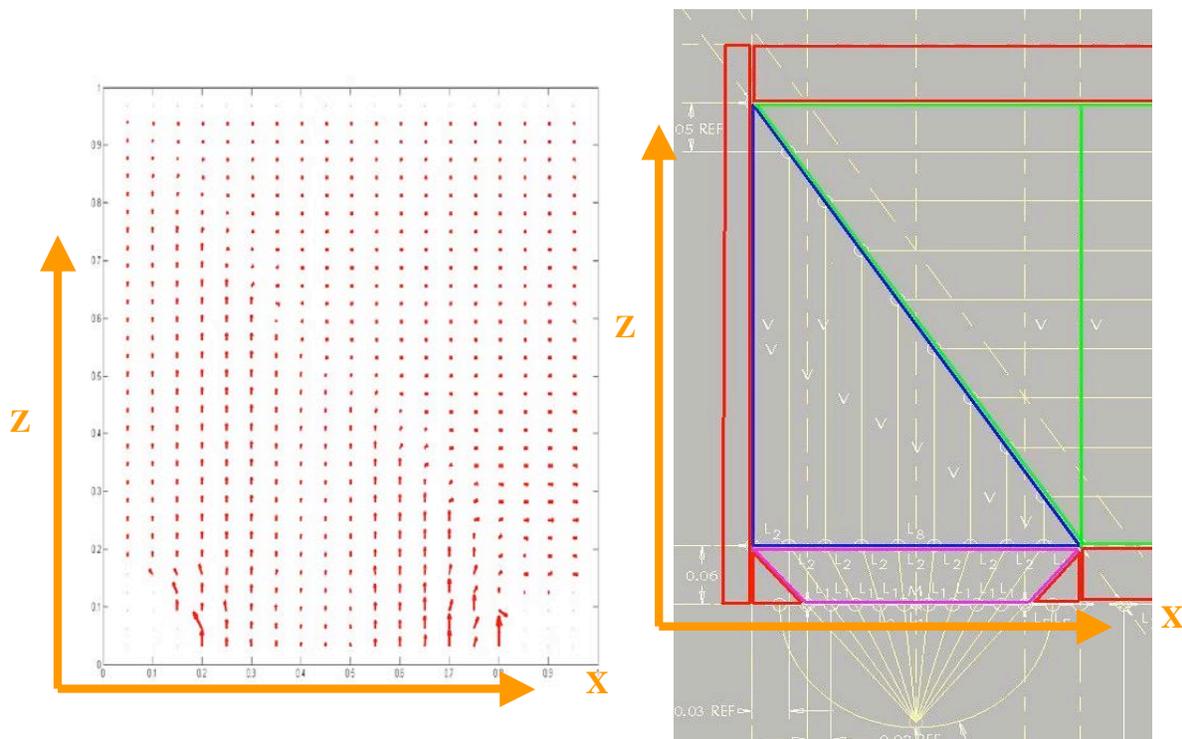


Fig. 5: Velocity flow field for MS inlet manifold (top left) and a sketch showing only the major permeability regions in MS inlet manifold (top right)

The fluid dynamics model for the helium plate side of the IHX is significantly simpler than the MS plate side because there are no complicated channel geometries that require multiple zoning. Developing the fluid dynamics model for the helium side should proceed quickly. Once that is complete, the thermal model for both manifolds will be developed and this too is expected to be relatively simple compared to the development of the MS plate side of the IHX. Once all three sections of the IHX have thermal and fluid mechanics computational models the three sections will be integrated by eliminating the boundary conditions that currently allow each section to run independently. The consolidated thermal and hydraulics model will be called the Compact Heat Exchanger

Explicit Thermal And Hydraulics (CHEETAH) code, which will provide a global transient temperature distribution for the IHX.

The global temperature distributions derived from the CHEETAH code will then be exported to a finite element analysis (FEA) software for mechanical stress analysis, also using the EPM method [1]. This FEA software will most likely be ANSYS. The resulting mechanical stress analysis will close the design optimization loop. The HX design will thus be made more robust in areas of high stress. The stress at the channel level will also provide insight into the possible creep effects at the channel level.

Work in the area of the intermediate loop transient thermal response consists of completing the current RELAP5-3D model by modeling pumps and the IHX with ramp down and natural convection flows in the IHX.

References

1. W. Huang, H. Zhao, and P.F. Peterson, "Multi-scale Stress Analysis for Compact Plate Heat Exchangers," 2006 International Congress on Advances in Nuclear Power Plants (ICAPP '06), Reno, NV, June 4-8, 2006.