CFD Analysis of a Printed Circuit Heat Exchanger

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Abstract

Introduction:
Very High-Temperature Gas-Cooled Reactor (VHTR) is a proposed Generation IV (Gen-IV) nuclear reactors by the Generation IV Forum. This reactor design is an advanced concept that has a much higher level of safety and reliability, as well as improved economic characteristics compared to existing nuclear power plants [1]. In addition, this plant design has a high reactor outlet temperature, allowing for process heat applications, such as hydrogen production, to be employed. Printed Circuit Head Exchangers (PCHEs), diffusion bonded plate type heat exchangers that have flow configurations chemically etched into each plate, have been identified as a promising candidate for use in advanced reactors (Figure 1). In this study, simulations will be run for various flow and temperature input configurations using COMSOL Multiphysics® software, and the results will be validated using experimental data obtained at an Ohio State experimental facility using helium gas as a coolant [2-4].

Use of COMSOL Multiphysics:
This study aims to characterize an effective means of simulating PCHE models. In the study, four different types of models will be tested, each with varying degrees of computational requirements (Figure 2). This study will utilize the COMSOL Multiphysics base package, as well as the CFD Module, the Heat Transfer Module, and the Structural Mechanics Module. The experimental data contains Reynolds Number flows ranging from 900 - 1500, requiring both laminar and turbulent models to be employed. In addition, the heat transfer module is required to couple the flow characteristics with the resulting heat exchanger thermal performance. Finally, the Structural Mechanics Module will be used to perform a thermal stress analysis.

Results:
Both models a.) and b.) from Figure 2 have been simulated in COMSOL using a laminar model. 100 test cases corresponding to the experimental tests were run using the parametric sweep feature in COMSOL. A swept meshing technique was employed to generate the mesh, and it consisted of around 900 thousand cells. Post processing of the data was completed and plots of friction factor (Figure 3) and Effectiveness (Figure 4) were created. The calculated friction factors for the cold side line up well. The hot side results indicate that a turbulent model may be necessary to model the hot channel bends. The experimental effectiveness trend matches the simulated results well. Research has been completed to suggest that in mini channel flows (Hydraulic Diameter less than 3 mm), as is the case for this study, early laminar to turbulent

transition occurs between Reynolds Numbers of 900 and 1500 [5]. Thus, a turbulent model will be employed to see if the simulated results better represent the experimental results.

Conclusion:
This study will help to characterize the performance and robustness of PCHEs, and will validate the use of COMSOL in simulation of PCHE performance. This study also holds broader implications in the field of fluid dynamics, as Nusselt Number correlations can be formulated and validated using local heat transfer coefficient calculations using the simulation results. Different PCHE geometries, such as zig-zag channels instead of straight channels, could also be investigated, helping to characterize the best parameters for PCHE performance.

Reference

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[3] S. Mylavarapu, “Development of Compact Heat Exchangers for Very High-Temperature Gas-Cooled Reactors”, Electronic Thesis or Dissertation (2008)

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[5] M. Rao and S. Khandekar, “Simultaneously Developing Flows Under Conjugated Conditions in a Mini-Channel Array: Liquid Crystal Thermography and Computational Simulations”, Heat Transfer Engineering, 751-61 (2009)

Figures used in the abstract

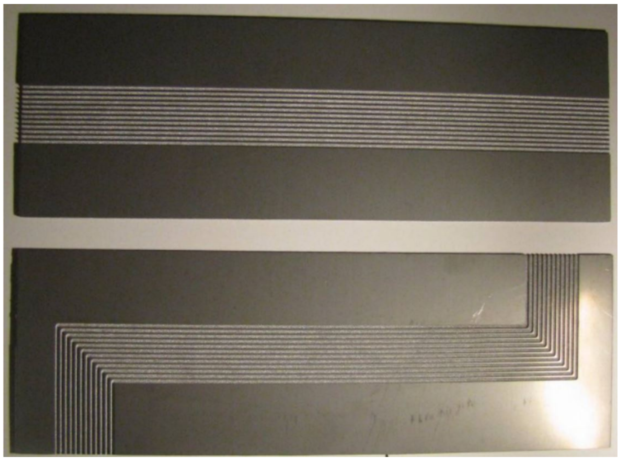

Figure 1: Cold (top) and hot (bottom) PCHE plates shown prior to the diffusion bonding process.

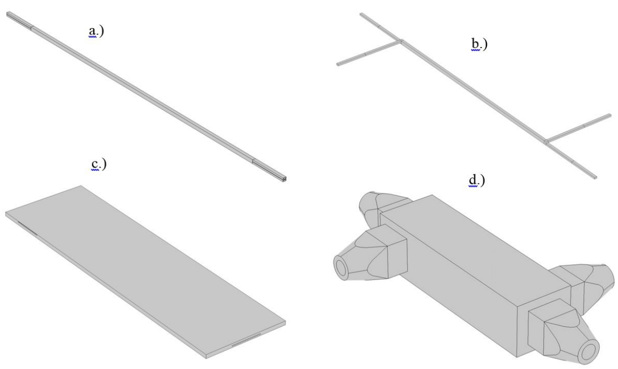

Figure 2: PCHE models to be tested; a.) Two channel excluding hot channel bend; b.) Two channel including hot channel bend; c.) Two plate model; d.) Full PCHE model including headers.

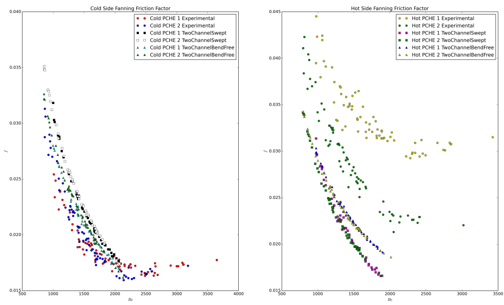

Figure 3: Cold (left) and hot (right) friction factor as a function of Reynolds Number

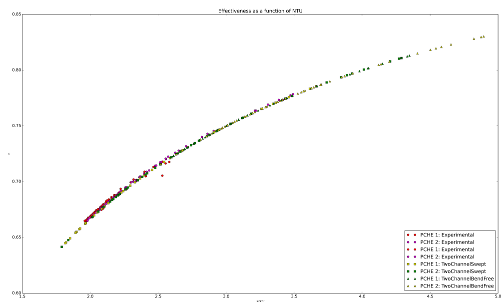

Figure 4: NTU-effectiveness plot for experimental and simulated results