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C3Or2C-04: Development of a High-Effectiveness Slotted Plate Cryogenic Heat Exchanger

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High-effectiveness heat exchangers are a ubiquitous component of cryogenic systems, but their performance typically falls short of model-based expectations. The following paper details modeling efforts of a heat exchanger designed to achieve an effectiveness in excess of 99% within a prescribed envelope of volume, weight, pressure drop, and operating conditions. Simulation efforts focus on employing minimal assumptions and accounting for many loss mechanisms to avoid overestimation of predicted effectiveness. Axial conduction and parallel passage flow imbalance are major contributing factors to heat exchanger inefficiency. Consequently, a staggered stacked slotted plate geometry, also known as a matrix heat exchanger, was chosen as the most promising type to achieve the desired effectiveness. High thermal conductivity, high surface area finned copper plates separated by low thermal conductivity, low cross-sectional area stainless steel spacers achieve high stream-to-stream heat transfer while limiting axial conduction and allowing for fluid redistribution between plates. The number of design parameters was reduced based on manufacturing limitations and conceptual reasoning. ANSYS Fluent computational fluid dynamics was used to form Nusselt number and Darcy friction factor correlations for the geometry and flow conditions. A finite difference MATLAB model accounted for axial conduction, parasitic heat loads, and material property variation with temperature and pressure. The Fluent-derived correlations were used as inputs to the MATLAB model. The MATLAB model was validated by comparing its results to an analytic, constant property effectiveness-NTU solution for stacked plate heat exchangers, as well as experimental data collected from a similar heat exchanger. Tradeoffs between weight, pressure drop, and effectiveness were studied.

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