ME PhD Thesis Colloquium

Hybrid Model of a Micro Channel Heat Exchanger used in a sCO2 Brayton Cycle

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ABSTRACT

Supercritical carbon dioxide (sCO2) Brayton cycle power plants are being extensively explored as viable alternatives to conventional steam Rankine power plants. Higher temperatures at the turbine exit in a sCO2 cycle provide better opportunities for heat recuperation resulting in significant improvement in cycle efficiencies. Studies have shown that micro channel heat exchangers (MCHEs) or commonly referred to as printed circuit heat exchangers (PCHEs) are suitable candidates for a recuperator and gas cooler used in a sCO2 power block. Both CFD and 1-d models-based unit-cell approach have been proposed in the literature for modeling and performance analysis of MCHEs. To estimate the heat exchanger size and arrive at an optimum channel configuration, CFD models are found to be computationally expensive and time-consuming, especially when full-scale MCHEs are to be modelled. On the other hand, 1-d models are inadequate for correctly estimating the stack size. The thesis aims to address this gap by proposing a hybrid model. The hybrid model utilizes the concept of Thermal Resistance Network (TRN) combined with a unit cell based CFD model to investigate the thermo-hydraulic performance of the complete MCHE stack. CFD based unit-cell models are developed for straight and non-straight channels to obtain correlations for Nusselt number and friction factors. A stack optimization strategy based on the rate of heat loss from the external surfaces of the MCHE core is presented to arrive at the optimum stack width, height, and number of rows. In addition, a comprehensive model for the inlet and exit manifolds utilizing the concept of flow resistances is developed to attain optimum pressure drops across the entry and exit manifolds. The manifold pressure balance scheme facilitates uniform flow distribution across all channels in the MCHE core. The efficacy of the hybrid model is presented for a recuperator and a gas cooler based MCHE used in a MW scale sCO2 Bryton power block. The TRN model coupled with CFD model and stack optimization algorithm using straight channels is used to arrive at optimum stack volume of the recuperator. The effect of channel hydraulic diameter and Reynolds number on corresponding pressure drop and effectiveness is demonstrated for a 5˚C pinch temperature differential. Improvement over the straight channel is demonstrated by using innovative configurations such as sinusoidal and zigzag flow paths. Variations in channel pressure drop obtained from the optimized stack and channel dimensions are used as inputs in the manifold model as constraining variables to obtain uniform pressure drop across all channels in the stack. Subsequently, the hybrid model is extended to model the gas cooler performance and obtain stack volume with water as the secondary heat transfer fluid. The effect of Reynolds numbers (both sCO2 and water) on stack size and performance is demonstrated for a temperature pinch of 3˚C at the cold inlet. Finally, multi-objective optimization is performed with pumping power and stack volume as objective functions to arrive at optimum channel dimensions and stack geometry. Unlike the recuperator where the mass flow rates across the hot and cold sides are identical, the water flow rate and the corresponding Reynolds number in the case of a gas cooler is dictated by sCO2 side

ABOUT THE SPEAKER

Vivek Pandey is a Direct PhD student working under the guidance of Dr. Pramod Kumar at the Dept. of Mechanical Engineering, IISc Bangalore. His research interests include, applied heat transfer, energy storage, thermal system design, compact heat exchangers, novel power cycles, and heat transfer enhancement mechanisms.

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