Half Array Architecture for Advancing Microchannel Heat Recuperation to Market

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Abstract

High temperature microchannel heat recuperators (HTμRs) offer an efficient means of improving reactor process thermal efficiency by offering smaller form factors due to increased heat transfer surface area density and volumetric heat transfer rate over traditional heat exchanger designs. To date, HTμRs face cost and reliability challenges. In this work, a HTμR design was developed capable of utilizing high volume manufacturing methods to improve raw material utilization and cost. The design utilizes a microchannel flow insert (MFI) to resist differential pressures within low pressure channels eliminating the need for photochemical machining. The MFIs are placed within a laser-welded microchannel "half array" which is inserted within a metal housing to establish the counterflow path. Analytical and computational models were developed to guide the structural, thermal and fluidic design of the sub-millimeter MFI for waste heat applications. A forming process was developed for producing the MFIs and experimental investigations were used to validate structural, thermal and fluidic performance. A robust microforming fabrication process was developed capable of providing average MFI heights of 529 μm with 0.5% standard deviation MFIs were analyzed for out-of-plane compressive stiffness and compressive strength over multiple loading cycles to validate both analytical and finite element models. A finite element model provided a model error of 6.8% for compressive stiffness. The unbonded μPTN design presented yields an 88% decrease in structural panel size compared to macro-pyramidal truss networks for a given loading condition while maintaining similar panel area.

Single layer fluid flow experiments were conducted to determine the average Nusselt number and pressure drop in microchannels both with and without an MFI installed. The MFI increased the average Nusselt number by 2.9x due to increased fluid mixing. The pressure drop through the MFI was found to be on average five times higher than the empty channel due to reduced flow cross-section area. The network pressure drop model yielded a percent error at low Reynolds numbers of 5.2%.

Subsequently, a 3.5kW HTμR made of Inconel 625 was designed for waste heat recovery with an inlet temperature of 850°C. A subscale HTμR was fabricated and tested to validate the 3.5kW design. The sub-scale five layer HTμR was tested with a hot side inlet temperature of 300 °C. The sub-scale device performed as expected in terms of effectiveness (4.3% error), duty (4.3% error), and MFI channel pressure drop (-2.6% error). These results were used to scale a 3.5kW Inconel 625 HTμR with a heat transfer surface area density of 1,633m^2/m^3, a volumetric heat transfer coefficient of 2.3 MW/(m^3 K), and a volumetric heat transfer rate of 32 MW/m^3 providing improved results versus high temperature recuperator designs in literature.

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