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ABSTRACT

The effect of minichannel geometry on the thermal and flow characteristics of a compact minichannel heat exchanger

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The aim of this study was to determine the effect of minichannel geometry, including channel dimensions, cross-sectional shape, and cross-sectional orientation relative to the heat transfer surface area, on the thermal and flow characteristics of a compact minichannel heat exchanger, and to establish the relationship between the thermal effect achieved and the energy required to drive the working fluids. An additional objective was to assess the possibility of the identification of a geometric configuration offering an optimal compromise between thermal, flow and performance index parameters.

A prototype of a single-plate minichannel heat exchanger of modular construction incorporating straight minichannels and two pairs of inlet and outlet plenums was designed and manufactured. Four variants of minichannel geometries were investigated: two variants of square cross-sections with dimensions of 1×1 mm and 2×2 mm, and two variants of rectangular cross-sections with dimensions of 1×2 mm and 2×1 mm. The rectangular configurations had the same hydraulic diameter with distinct orientation of their cross-sections relative to the flow direction. In order to minimize the influence of factors other than minichannel geometry, the channel length and the overall dimensions of the heat exchanger components were kept constant. An experimental test stand was constructed and validated to determine the thermal and flow parameters of the heat exchanger. The heat transfer rates, overall heat transfer coefficients, pressure drops, pumping powers, Reynolds, Péclet, and Graetz numbers, effectiveness, and thermal and hydrodynamic performance parameters were determined. The experimental results were presented for approximate Péclet numbers on the hot and cold sides of the investigated heat exchanger in order to compare flow and heat-transfer conditions across the investigated minichannel geometries.

An analytical heat transfer model was developed altogether for the inlet and outlet plenums and the minichannels regions. The model was developed according to the assumptions of three-sided heating in minichannels and thermally developing flow conditions. The total thermal resistance and the overall heat transfer coefficient were determined analytically and compared with experimental results. From the comparison it was revealed that the analytical

model correctly projected the experimental result trends for all investigated geometries and the degree of fit depended on the minichannel geometry. The occurred discrepancies between results obtained experimentally and analytically may arise from the limitations of the used Nusselt number correlations, the influence of entrance effects, non-uniformities in assumed boundary conditions as well as the development of the hydrodynamic and thermal boundary layers.

The conducted analysis demonstrated that no single geometric configuration could be explicitly identified as providing the highest heat transfer rate, overall heat transfer coefficient, and thermal effectiveness, while maintaining low pressure drops and low pumping power. The minichannel geometry selection is a multi-objective optimization problem and the assessment of the balance of thermo-hydraulic and energy-related parameters depend on the adopted evaluation criterion. Nevertheless, when considering the structural features of investigated prototype it was proven that the developed minichannel heat exchanger is characterized by simple and compact design, significant heat transfer intensification and relatively low flow resistance. Therefore, the proposed design of minichannel heat exchanger may provide a promising solution in the field of compact heat exchangers, however, direct comparison with other geometries require the consideration of design constraints and operating conditions.