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Degradation of the performance of microchannel heat exchangers due to flow maldistribution

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ABSTRACT

The effect of flow maldistribution on the performance of microchannel parallel plate heat exchangers is investigated using an established single blow numerical model and cyclic steady-state regenerator experiments. It is found that as the variation of the individual channel thickness in a particular stack (heat exchanger) increases the actual performance of the heat exchanger decreases significantly, deviating from the expected nominal performance. We show that this is due to both the varying fluid flow velocities in each individual channel and the thermal cross talk between the channels transverse to the direction of the flow.

1. Introduction

Microchannel heat exchangers show promise of theoretically large heat transfer coefficients and provide the ability to design compact devices. These are two very central parameters in the areas of, e.g., cryocoolers, dehumidifiers, Stirling engines, solar power, electronics cooling and magnetic refrigeration [1–7].

Parallel plate heat exchangers are considered, from a theoretical standpoint, to have a good ratio between heat transfer properties and pressure drop. In order to reach sufficient values of the number of transfer units (*NTU*) and heat transfer coefficient, h, the flow channels defined by the parallel plates, or similar geometries, must be made into the sub-millimeter regime. This is due to the fact that, assuming a constant Nusselt number, the only parameter that can increase h is a decrease in the hydraulic diameter, d_h. The required flow rate, specified through operating frequency and thermal utilization of the heat exchanger, defines a minimum value of h and thus d_h for a given value of the *NTU*. In many applications it is therefore important to have quite small channels (hydraulic diameters down to or even below 100 μm are not unrealistic for many applications) [8].

The range of hydraulic diameters from 1 μm to 1 mm is commonly defined as microchannels [9]. Significant discrepancies are, however, often observed between experiments and theory in this range. This has led to a quite significant amount of research into various aspects of the governing physics at the relevant scales.

1.1. Relevant physical effects at the microscale level

Several explanations for the relatively large deviations of the predicted heat transfer performance and that experimentally observed on the microscale have been suggested. These include physical effects not previously considered such as, e.g., whether the continuum assumption breaks down, the influence of surface roughness in the channels etc. In Ref. [9] these issues are reviewed and it is concluded that for incompressible laminar flows with aqueous fluids no new physical phenomena happen in microchannels. This is supported by careful experiments performed on single channel tubes and square channel heat exchangers in the microchannel range [9–11].

A range of assumptions are usually made in order to model the coupled fluid flow and heat transfer problem in heat exchangers in general. These issues are discussed in great detail in [9] and references therein. Here, they are summarized:

- Entrance effects
- Temperature dependent properties
- Viscous dissipation
- Surface roughness

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