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Single-phase ambient and cryogenic temperature heat transfer coefficients in microchannels

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Micro-scaling cryogenic refrigerators, in particular the Joule-Thomson (JT) variety requires very good information about heat transfer characteristics of the refrigerants flowing in the microchannel for optimal design and performance. There are numerous studies regarding heat transfer coefficient measurements of liquid flow in microchannels at/near ambient temperature and high Reynolds flow (Re>2000), that well agree with the conventional correlations. However, results from these studies of gaseous flow in microchannels at low Reynolds flow (Re<1000) disagree with conventional theory. Moreover, the studies performed at cryogenic temperatures are quite limited in number. Because extremely low Reynolds flow is present when micro-scaling a cryogenic JT refrigerator to MEMS fabrication levels, due to low pressure ratios provided by a single stage MEMS compressor the heat transfer characteristics at these conditions require investigation. In this paper, the single-phase heat transfer coefficients and friction factors for nitrogen are measured at ambient and cryogenic temperatures. The hydraulic diameters for this study are 60, 110 and 180 μm for circular microchannels. The Reynolds numbers varied from a very low value of 10 to 3000. The measured friction factors are comparable to those in macro-scale tubes. The experimental results of the heat transfer indicate that Nusselt numbers derived from measurements are significantly affected by axial conduction at low Reynolds flow (Re<500). The Nusselt numbers at high Reynolds flow (Re>1000) follow conventional theory. The detailed experiment, procedure, and measured results are presented in this paper and discussed regarding deviation from ideal theory at low Reynolds flow.

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