Two-Phase Pressure Drop Correlation During the Convective Condensation in Microchannel Flows

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Abstract.

This paper presents the experimental results on two-phase pressure drop related to microchannel flows during convective condensation. Two pumping systems, one being on a capillary pumped loop (CPL) mode and the other being with a magnetic driven pump with variable flow rate, were used in the experimental apparatus to test microchannel condensers with methanol as the working fluid. Tests were conducted for two different saturation temperatures, for a range of heat dissipation rate from 20 to 350 W, four microchannel condensers and mass flow rates of up to 600 kg/m2 s. The results showed that the microchannel condensers presented high pressure drop (up to 63 kPa) for the mass flow rate applied, which is mainly related to the microchannels reduced geometry. The levels of pressure drop observed were also considered high, as only laminar flow was verified during the tests. A correlation for the two-phase multiplier was obtained to correlate the experimental data, which showed to predict 85 % of the experimental results within an error range of less than 35 % for both saturation temperatures tested. The obtained correlation presented very high sensibility when calculating the pressure drop along the microchannels, considering the geometric factors and heat transfer capabilities of such equipment, which was able to present a good correlation with the experimental data.

Keywords: convective condensation, microchannels, thermal control, pressure drop.

Introduction

The continuing miniaturization of electronic devices and systems has made area restrictions for the heat to be dissipated a significant problem. This issue becomes more important when considering that the device performance and reliability are known to increase when operating temperatures are kept below 80 $^{\circ}$C. Investigations and applications using forced-air convection and pool boiling for electronics cooling have been performed, proving to be efficient on the thermal management, but limited heat dissipation rates and system integration are still a concern. Tuckermann and Pease [1] first proposed a cooling system for electronic devices using microchannel flows for forced single-phase liquid. This technology demonstrated to be promise for more compact arrangements of electronic devices and cooling systems in future electronic packaging. Based upon initial findings, a compact heat-sink microchannel was found to offer new degrees of freedom for system designs with considerable higher heat dissipation rates, but very significant high-pressure drop penalty. Focusing on such a problem, this paper presents an investigation to contribute to the understanding in two-phase pressure drop in microchannel flows. Four different microchannel heat exchangers were experimentally tested for condensing two-phase flow, in order to determine the mean pressure drop and to further develop a correlation. This procedure has the objective of helping future microchannel heat exchangers designs, to improve electronics and capillary pumping systems cooling.

Experimental Apparatus

To test the microchannel condensers, two pumping methods were used: the first was a capillary evaporator (Fig. 1a) and the second was a magnetic driven pump (Fig. 1b) in conjunction with a flow through evaporator. The capillary evaporator was used for testing at low flow rates along the condensation section, while the mechanic pump promoted higher flow rates. The condensers were designed considering that, as the channel size decreased the number of parallel channels increased. For the tests when higher flow rates had to be reached, a leak-free magnetic driven pump with speed control was used. This pump allowed controlling the flow rate up to a maximum of 3 l/min for a maximum pressure drop of 275 kPa. The details on the design for the loop used for testing the microchannel condensers are presented by Riehl (2000).
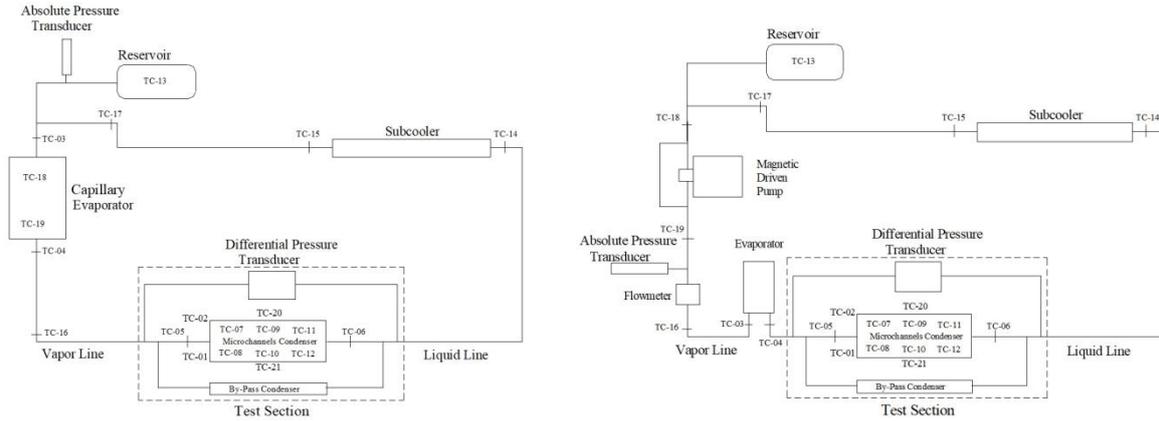
Figure 1. Experimental tests apparatuses.

Results and Discussions

In case of evaluating the single-phase pressure drop for the liquid, the two-phase multiplier would be represented as ϕ_l^2 and, for the vapor, ϕ_v^2. From the experimental results, an empirical relation for the two-phase multiplier for the liquid that showed better correlation is presented as:

$$\phi_l^2 = \left(1 + 10X^{0.188} + X^{2.0}\right)^{0.5}, \tag{1}$$

where X is the Martinelli Parameter defined as:

$$X^2 = \left(\frac{1-x}{x}\right)^{2-n}\left(\frac{\rho_v}{\rho_l}\right)\left(\frac{\mu_l}{\mu_v}\right)^n, \tag{2}$$

Equation (1) was compared against the experimental results for the pressure drop for both saturation temperatures and condensers. Figure 2 presents the comparisons for T_{sat}=45 and 55 °C.
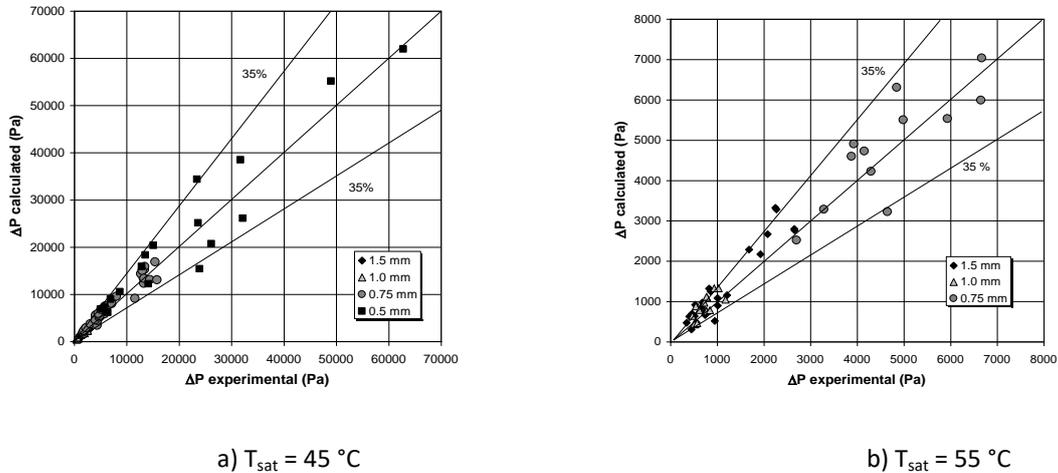

a) T_{sat} = 45 °C   b) T_{sat} = 55 °C

Figure 2 – Comparison of the experimental results for pressure drop and Eq. (3).

Conclusions

A correlation to predict the pressure drop, using the two-phase multiplier from the Separated Flow Model, was derived. The two-phase multiplier correlation, represented by Eq. (3), provided good agreement with all experimental results for both saturation temperatures used, which correlated 85% of the experimental data within an error of +/- 35%.

References

[1] Tuckermann, D. B.; Pease, R. F. W., 1981, "High-Performance Heat Sinking for VLSI", IEEE Electron Device Letters, Vol. EDL-2, No.5, pp. 126-129.