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Experimental study on condensation heat transfer in vertical minichannels for new refrigerant R1234ze(E) versus R134a and R236fa

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ABSTRACT

Experimental condensation heat transfer data for the new refrigerant R1234ze(E), trans-1,3,3,3-tetrafluoropropene, are presented and compared with refrigerants R134a and R236fa for a vertically aligned, aluminum multi-port tube. Local condensation heat transfer measurements with such a multi-microchannel test section are very challenging due to the large uncertainties related to the heat flux estimation. Presently, a new experimental test facility was designed with a test section to directly measure the wall temperature along a vertically aligned aluminum multi-port tube with rectangular channels of 1.45 mm hydraulic diameter. Then, a new data reduction process was developed to compute the local condensation heat transfer coefficients accounting for the non-uniform distribution of the local heat flux along the channels. The condensation heat transfer coefficients showed the expected decrease as the vapor quality decreased (1.0–0.0) during the condensation process, as the mass velocity decreased (260–50 kg m^{-2} s^{-1}) and as the saturation temperature increased (25–70 °C). However, the heat transfer coefficients were not affected by the condensing heat flux (1–62 kW m^{-2}) or by the entrance conditions within the tested range. It was found that the heat transfer performance of R1234ze(E) was about 15–25% lower than for R134a but relatively similar to R236fa. The experimental data were then compared with leading prediction methods from the literature for horizontal channels. In general, the agreement was poor, over-predicting the high Nusselt number data and under-predicting the low Nusselt number data, but capturing the mid-range quite well. A modified correlation was developed and yielded a good agreement with the current database for all three fluids over a wide range of operating conditions.

1. Introduction

Condensation in mini- to microchannels seems prominent for various applications, such as air-conditioning systems in automobiles and two-phase cooling systems for computers and power electronics, due to its high effectiveness and the compact size of such condensers. However, condensation heat transfer in mini- to microchannel depicts a different behavior than in macrochannels according to numerous previous experimental studies. Thus, not surprisingly, the existing condensation heat transfer prediction methods developed with macroscale data seem to be unable extrapolated well to predict mini- to microchannel data. For instance, Garimella [1] reviewed a large number of the existing studies on mini- to microchannel condensation covering the flow pattern, void fraction, pressure drop and heat transfer prediction methods. Another comprehensive review of macroscale condensation studies can be found in Thome [2].

Several pioneering works on minichannel condensation were conducted by the research group lead by Webb [3–7]. Webb and Zhang [3] evaluated the existing correlations, at the time of their study in 1998 and suggested that the previous prediction methods developed in macroscale tubes failed to predict their minichannel data. Moser et al. [6] developed an equivalent Reynolds number model based on the heat-momentum analogy using the relationship between the heat transfer coefficient and the wall shear stress. The equivalent Reynolds number was defined by assuming a liquid-only artificial condition providing an equivalent interfacial shear stress. This model was validated by a large database from 18 sources for channel diameters from 3.14 mm to 20 mm. The various types of multi-port flat extruded aluminum tubes used in their research have been also extensively tested at different flow conditions by other researchers, such as Kim et al. [8,9] and Koyama et al. [10,11].

More recently, experiments in various cross-sectional channels including triangular, N-shape, and W-shape have been reported by the research group lead by Garimella [1,12–17]. The test facility developed by their group uses an innovative test method with a secondary fluid loop to amplify the temperature difference in the

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