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Performance characterization of R134a and R245fa in a high aspect ratio microchannel condenser

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ABSTRACT

An experimental study on parametric characterization of two-phase condensing flows of refrigerants R134a and R245fa in a single microchannel was carried out utilizing a microchannel with a cross-section of 0.4 mm × 2.8 mm (7:1 aspect ratio) and length of 190 mm. The study investigated parametric effects of variations in saturation temperatures between 30 °C and 70 °C, mass flux between 50 and 500 kg m^{-2} s^{-1}, and inlet superheats between 0 °C and 20 °C on the average heat transfer coefficient and overall pressure drops in the microchannel. The results of the study suggest that while the saturation temperature and mass flux have a significant effect on both the heat transfer and overall pressure drop coefficients, the inlet superheat has little or no effect. In addition, the applicability of the Dobson–Chato correlation for heat transfer coefficient and Lockhart–Martinelli correlation for pressure drop for the range of parameters was investigated.

Caractérisation de la performance du R134a et du R245fa dans un condenseur à microcanaux avec un rapport longueur-diamètre élevé

Mots clés : Condensation ; Microcanaux ; Coefficient de transfert de chaleur ; Chute de pression ; Expérimentation ; Corrélations

1. Introduction

The ability of microchannels to provide high surface area-to-volume ratios, high heat transfer coefficients, high efficiencies and system compactness are among the major advantages of microchannels for use in a diverse range of industries. Condensation heat transfer in micro- and mini-channels is naturally of great practical importance in development of next generation ultra-compact and high performance two-phase flow thermal systems. But compared to the evaporation phenomenon, condensation in microchannels has been the subject of fewer studies. It can be argued that these two phenomena are essentially similar, and this may be true to some extent. However, in condensation, nucleation sites are

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Nomenclature

A_{cs}	channel surface area [m^2]
C_p	specific heat capacity [J kg^{-1} K^{-1}]
D_h	hydraulic diameter [m]
f	friction factor [-]
G	mass flux [kg m^{-2} s^{-1}]
h	heat transfer coefficient [W m^{-2} K^{-1}], specific enthalpy [J K^{-1}]
k	thermal conductivity [W m^{-1} k^{-1}]
L	length, channel length [m]
$\dot{m}$	mass flow rate [kg s^{-1}]
P	pressure [Pa], perimeter [m]
Pr	Prandtl Number [-]
$\dot{Q}$	heat transfer rate [W]
Re	Reynolds number [-]
T	temperature [K]
t	thickness [m]
x	thermodynamic vapor quality [-]

Greek characters

μ	viscosity [kg m^{-1} s^{-1}]
ρ	density [kg m^{-3}]
Φ^2	two-phase multiplier for frictional pressure drop [-]
χ_{tt}	Martinelli's parameter

Subscripts

avg	average value
c	channel
cupper	Cupper material
i	internal, inlet
l	liquid phase
o	outlet
r	refrigerant
sat	saturation
SH	superheat
v	vapor phase
W	wall
water	water side

not present, and this fact alone can cause substantial differences in the physics of the phenomenon. Accordingly, the main aim of the current study was to characterize the condensation heat transfer performance of two selected refrigerants in a single flat-plate, micro-channel condenser. A brief review of relevant literature is given in the following.

Numerous condensation experimental studies have been done to measure heat transfer rate and pressure drop in conventional macro-channels, and several correlations for predicting these parameters have been proposed.

Riehl et al. (1998) reviewed single-phase and two-phase flow heat transfer coefficients of experimental data obtained for microchannels and compared them to the available analytical models. The comparisons showed large discrepancies. The models they examined were not able to predict the experimental data accurately. Furthermore, correlations of microchannel convective flow also showed wide discrepancies. Later Riehl and Ochterbeck (2002) presented experimental results of condensation using methanol as the working fluid. The experiments were conducted for two different saturation temperatures, range of heat dissipation rate from 20 to 350 W and four microchannel condensers with channel diameters between 0.5 and 1.5 mm. All the channels had aspect ratios of 1. Their results showed high heat transfer coefficients with Nusselt numbers ranging from 15 to 600. They also obtained a Nusselt number correlation which was able to predict 95% of the data within 25% error band.

Cavallini et al. (2002) investigated condensation of R123a, R125, R410a, R32, R236ea and R22 inside a round tube with 8 mm inner diameter while varying the mass flux from 100 to 750 kg m^{-2} s^{-1}. The study intended to improve Friedel's correlation (1979) in the annular regime. They also used the dimensionless vapor velocity to distinguish between the different flow regimes that exist in condensation. Then new constants were fitted to the Friedel's correlation from the study of the annular regime, and due to the insignificant effect of gravitational forces in the annular flow regime, the Froude number was not accounted for in the two-phase multiplier correlation. However, these predictions cannot be applied to flow transitions.

Kim et al. (2003a, b), studied condensation in flat aluminum multi-channel tubes using R410A and R22. The tubes had two internal geometries: one with a smooth inner surface (D_h = 1.41 mm), the other with a micro-finned inner surface (D_h = 1.56 mm). Their results showed that for the smooth tube, the heat transfer coefficient of R410A was slightly larger than that of R22. For the micro-finned tube, however, the trend was reversed. They also compared their data with Webb's (1999), Koyama et al.'s (2003a, b), Akers et al.'s (1959) and Shah's (1979) correlations and concluded that for the smooth tube, Webb's correlation predicted the data reasonably well. For the micro-finned tube, they modified Yang and Webb's (1997) model to correlate with their data. The modified model predicted the data within 30%.

El Hajal et al. (2003) and Thome et al. (2003) studied condensation of 15 different fluids amongst which were pure refrigerants and refrigerant blends. They used the studies of Kattan et al. (1998a, 1998b, 1998c) of evaporating refrigerants to develop a flow regime map and a heat transfer model. In this study they observed the following regimes: bubbly flow, intermittent, annular, stratified wavy, fully stratified and mist. However, the model did not include the bubbly flow regime. They suggested that heat transfer occurred due to two types of mechanisms: film and convective condensation. The regimes that contributed to convective condensation were annular, mist and intermittent flows, whereas stratified-wavy and stratified flows were governed by both mechanisms. The developed correlation of heat transfer coefficient was governed by the interfacial friction factor, Prandtl number and Reynolds number.

Garimella et al. (2005, 2002) experimentally evaluated different shapes and sizes of micro and mini-channels for pressure drop and heat transfer of a condensing flow. The channels' hydraulic diameters ranged from 0.4 to 5 mm for qualities ranging from 0% to 100% and mass fluxes between 150 kg m^{-2} s^{-1} and 750 kg m^{-2} s^{-1}. They developed a model for