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Pressure drop during condensation of R-134a inside parallel microchannels

G. Goss Jr.[a], J.L.G. Oliveira[b], J.C. Passos[a,*]

[a] Mechanical Engineering Department, LEPTEN/ Boiling, Federal University of Santa Catarina, Florianópolis, SC, 88040-900, Brazil

[b] Mobility Department, Federal University of Santa Catarina, Joinville, SC, 89218-000, Brazil

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ABSTRACT

In this study, we experimentally investigate the pressure losses during the convective condensation of R-134a inside eight circular (diameter $D = 0.77$ mm) horizontal and parallel microchannels. All pressure loss contributions, including the ones related to expansion, contraction, flow direction change, acceleration, and friction, are quantified for microchannel arrangement. The test conditions include the pressure, vapor quality, heat flux, and mass velocity, ranging from 7.3 to 9.7 bar, 0.55 to 1, 17 to 53 kW m^{-2}, and 230 to 445 kg m^{-2} s^{-1}, respectively. The frictional pressure drop roughly corresponds to 95% of the net pressure loss. The influence of temperature, heat flux, and mass velocity on the pressure drop is evaluated. The results show that the pressure drop increases with an increase in mass velocity and a decrease in saturation temperature, whereas it is not affected as much by the heat flux. The experimental results are compared with correlations and semi-empirical models described in the literature. Correlations based upon the adiabatic two-phase flows within bore pipes can reasonably predict the pressure drop for condensing microchannel flows. The model proposed by Cavallini et al. (2006) presents the best prediction performance.

Chute de pression durant la condensation du R-134a à l'intérieur de microcanaux parallèles

Mots clés : Microcanaux ; Chute de pression ; Condensation convective

1. Introduction

The need for more efficient heat transfer systems, in order to reduce electricity consumption and CO_2 emissions, has motivated microchannel condensation research in the last twenty years. New heat exchanger generations are expected to be more effective and compact (towards miniature structures). One consequence of the miniaturization of condensers in air-cooled refrigeration systems, for example, is an increase

* *Corresponding author*. Tel.: +55 48 91191158.
E-mail addresses: gil.goss@geoenergy.com.br (G. Goss), jorge.goes@ufsc.br (J.L.G. Oliveira), julio.passos@ufsc.br (J.C. Passos).
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Nomenclature

A	area
A_1, A_2, A_3, A_4	Cavallini et al. (2006) constants
ADM	absolute mean deviation
C_c	contraction coefficient
C_o	confinement number
c_p	specific heat at constant pressure
D	hydraulic diameter
E	liquid entrainment parameter
E_o	Eötvos number
f	Fanning friction factor
g	gravitational acceleration
G	mass velocity
h	enthalpy
h_{lv}	vaporization enthalpy
j	superficial velocity
K_{90}	coefficient for flow direction change of 90°
L	length
m	mass flow rate
M_n	number of experimental runs
n	segment number
N	total number of segments
p	pressure
P_{ent}	Pressure at the microchannel inlet
ΔP	pressure drop
q_m	mean heat flux
Q_f	total heat flux removed by the Peltier system
Re	bulk Reynolds number based on pipe hydraulic diameter
S	slip ratio
T	temperature
x	vapor quality
z	stream-wise coordinate

Greek symbols

α	void fraction
γ	cross-section ratio between microchannel and manifold
ζ	flow resistance coefficient
μ	dynamic viscosity
ρ	mass density
ρ_{vc}	mass density as proposed by Paleev and Filippovich (1966)
σ	surface tension
Φ	pressure drop multiplier
ψ_s	two-phase multiplier

Subscripts

$2P$	two-phase
90	flow direction change of 90°
$crit$	critical
exp	expansion
h	homogeneous
L	Liquid
LO	liquid only in entire pipe
sat	saturation
sup	superheating
TP	two-phase
v	vapor
vO	vapor only in entire pipe

in the COP (Coefficient of performance) caused by a decrease in the pressure drop on the air side and an increase in the heat transfer coefficient on the refrigerant side. However, it can also lead to an increase in the pressure drop in the refrigerant flow; Goss and Passos (2013).

Micro condensers are found in a multitude of applications, namely, cooling and refrigeration processes, compact heat exchangers in the electronics industry, thermal control in satellites, and compact air conditioning for automotive industry. See Chen et al. (2014a) and Wang and Rose (2011). In these applications, condensation in microchannels is a key element in the development of more efficient heat exchangers.

Microchannel condensation was intensively researched by Ghiaasiaan (2008) and Garimella (2006). However, the phase change within micro-geometries is not comprehensive. The lack of consensus in the heat transfer and pressure drop models is evident from the different results obtained by the authors. See the work of Dalkilic and Wongwises (2009), for example.

At microscale, the shear and surface tension forces become more important than the gravitational forces, whereas the opposite holds true when the diameter is large. As reported in Agarwal et al. (2010), Cavallini et al. (2006), Mghari et al. (2014), Coleman and Garimella (2000, 2003) and Chen et al. (2014b). These differences motivated the investigation of several features of two-phase flows in microchannels, including the two-phase pressure drop (*i.e.,* Kim et al. (2012) and Fourar and Bories (1995)) and flow regime transitions during condensation; Nema et al. (2014) and Doretti et al. (2013).

Pressure drop is a key hydrodynamic parameter in microchannel arrangements. It is an essential element in the design of piping and process systems. However, most of the correlations proposed to predict two-phase frictional pressure drop during condensation in microchannels are based on modifications from the Lockhart and Martinelli (1949), Chisholm (1973) and Friedel (1979) correlations, which were proposed for channels and pipes with several mm of diameter or larger. More recent numerical models and experiments only attempt to estimate the frictional pressure drop in microchannel arrangements; *e.g.* Ganapathy et al. (2013) and Al-Hajri et al. (2013). Investigation of other pressure drop amounts such as the ones related to expansion and contraction were hardly performed in condensing flows; see Huang et al. (2014), for example. This study will provide the order of magnitude of all pressure drop terms of an arrangement consisting of parallel microchannels connected to common headers through a dedicated experiment. This evaluation is of course more interesting if performed with practical refrigerants as R134a.

The objective of this study is to experimentally study pressure drop during convective condensation of R-134a inside eight circular (diameter $D = 0.77$ mm) horizontal and