INTERNATIONAL JOURNAL OF REFRIGERATION 67 (2016) 373–382

Available online at www.sciencedirect.com

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Experimental investigation on the thermodynamic performance of double-row liquid–vapor separation microchannel condenser

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A R T I C L E I N F O

Article history:
Received 8 September 2015
Received in revised form 23 February 2016
Accepted 28 February 2016
Available online 4 March 2016

Keywords:
Double-row liquid–vapor separation microchannel condenser
Thermodynamic performance
Penalty factor
Minimum entropy generation number

A B S T R A C T

A double-row liquid–vapor separation microchannel condenser (D-LSMC) was presented, and its tube pass scheme was optimized using the theoretical method. A series of experiments were conducted to investigate the heat load, average heat transfer coefficient (AHTC), and pressure drop of the optimal D-LSMC. Experimental results were compared with an optimal common double-row parallel-flow microchannel condenser (D-PFMC). The findings showed that, at the inlet mass flux of 585 $kgm^{-2}\,s^{-1}$ to 874 $kgm^{-2}\,s^{-1}$, the AHTC of the D-LSMC was 3.3%–14.4% higher than that of the D-PFMC. However, the pressure drop of the D-LSMC was only 43.4%–52.1% of that of the D-PFMC. The heat exchange capacity of the back row was weaker by almost half of that of the front row. In addition, the tube wall temperature of the back row decreased faster than that of the front row, which indicated that the back row had a larger pressure drop. The minimum entropy generation number (Ns) was used to evaluate the D-LSMC and the D-PFMC, which indicated the greater thermodynamic performance of the D-LSMC.

Étude expérimentale de la performance thermodynamique d’un condenseur à microcanaux de séparation liquide-vapeur à double-rangée

Mots clés : Séparation liquide-vapeur à double rangée ; Condenseur à microcanaux ; Performance thermodynamique ; Facteur de pénalité ; Nombre minimal de production d’entropie

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http://dx.doi.org/10.1016/j.ijrefrig.2016.02.020

Nomenclature

Abbreviation

D-LSMC	double-row liquid–vapor separation microchannel condenser
D-PFMC	double-row parallel-flow microchannel condenser
Ns	minimum entropy generation number
LSC	liquid–vapor separation condenser
PF	penalty factor
AHTC	average heat transfer coefficient

Symbols

H_a	height of microchannel tube [mm]
L	length of microchannel tube [mm]
ρ	density [kgm^{-3}]
c_p	isobaric heat capacity [$Jkg^{-1} K^{-1}$]
G	mass flux [$kgm^{-2} s^{-1}$]
αi	condensation heat transfer coefficient [$kWm^{-2} K^{-1}$]
DT_{dr}	driving temperature difference [K]
h	specific enthalpy [Jkg^{-1}]
S	entropy [JK^{-1}]
N	tube number
Ra	gas constant of air [$Jmol^{-1} K^{-1}$]
H_b	width of microchannel tube [mm]
δ	thickness of tube wall [mm]
x	vapor quality
d_h	hydraulic diameter [mm]
T	thermodynamic temperature [K]
Q	heat load [W]
q''	heat flux [Wm^{-2}]
Ai	heat transfer area of in-tube [m^2]
DT_{sr}	condensing temperature drop [K]
dp/dz	unit length pressure drop [Pam^{-1}]

Subscripts

in, out	inlet, outlet
r, air	refrigerant, air
w	tube wall
row1	front row
l, v	liquid phase, vapor phase
m	average, middle section
I	order number
row2	back row

1. Introduction

The air-cooled condenser is an important device of the refrigeration system. In the 60s, Kays and London (1964) found that reducing the diameter of the tube can increase the heat transfer coefficient, and the microchannel condenser was investigated widely.

Much research has been conducted on the performance of the single-row microchannel condenser. Ebrahim et al. (2013) experimentally studied the condensing characteristic of the two-phase flows with R134a and R245fa in a microchannel condenser, whose microchannel had a cross-section of 0.4 mm × 2.8 mm. The condenser was tested at saturation temperatures of 30 °C–70 °C, mass flux of 50 $kgm^{-2} s^{-1}$–500 $kgm^{-2} s^{-1}$, and inlet superheat of 0 °C–20 °C. They found that condensing temperature and mass flux have significant effects on the thermodynamic performance, whereas inlet superheat has little effect on the thermodynamic performance. Wang et al. (2015) studied the effects of the condenser aspect ratio and mass flux on refrigerant flow distribution, heat transfer, and refrigerant-side pressure drop. The thermodynamic performances of four condensers were predicted and tested experimentally. Moreover, 66 condensers with different aspect ratios were evaluated theoretically. They found that the uniform distribution model and the mal-distribution model had a maximum error of 19.40% and 14.31% on pressure drop, respectively. In addition, an increase in the condenser aspect ratio improves the refrigerant uniformity, and the heat transfer exhibits only 2.6% change under various aspect ratios. The tube pass scheme also strongly affects the performance of the microchannel condenser. Bullard et al. (2006) studied microchannel condensers, whose tube had an inner diameter of 1.9 mm, using the numerical simulation method. They obtained a three-pass optimal tube pass scheme microchannel condenser, whose tube numbers were 38, 24, and 9 in ascending order passes. Chung et al. (2002) used the augmented Lagrange multiplier method (ALM) to find a four-pass optimal tube pass scheme microchannel condenser. They found that the optimal scheme 9-8-5-5 resulted in the lowest pressure drop, which was 85.5% and 83.3% of the general schemes 11-7-5-4 and 9-8-6-4, respectively.

In recent years, some researchers have studied the air-side performance of the double-row or multi-row microchannel condenser (Davenport, 1983; Kim and Bullard, 2002; Park and Jacobi, 2009; Wang et al., 1996, 1999). Liang et al. (2015) experimentally investigated the double-row microchannel heat exchanger and tested the heat capacity and pressure loss of heat exchangers with different fin heights of 5.4 and 8 mm. They found that the heat capacity of the device with a fin height of 5.4 mm is 3.0%–8.6% higher than that with a fin height of 8 mm. Byun and Kim (2015) studied the two phase distribution in a double-row/four-pass microchannel heat exchanger with the pass scheme 10-12-12-10 and investigated the configuration of the row-crossing header and mass flux. At a mass flux of R410A from 70 $kgm^{-2} s^{-1}$ to 130 $kgm^{-2} s^{-1}$, the liquid distribution improved with an increase in the mass flux, and the row-crossing header greatly affected the flow distribution of the back row. However, most studies focus on the air-side performance and refrigerant flow distribution of the double-row microchannel condenser, and only few studies do so on the thermodynamic performance of the tube side.

Wu et al. (2010) presented the liquid–vapor separation condenser (LSC), which utilized the liquid–vapor separation to enhance the vapor quality and improve the thermodynamic performance. We (Zhong et al., 2014) studied the single-row optimal LSC and found that it could reduce a large-scale pressure drop, in contrast to the condenser without a liquid–vapor separation condenser. However, under experimental condition, the AHTC of the LSC was lower than that of the common parallel-flow condenser at small-scale mass fluxes