Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

Review

Flow condensation heat transfer correlations in horizontal channels

Helei Zhang [a], Xiande Fang [a,*], Hui Shang [b], Weiwei Chen [a]

[a] Institute of Air Conditioning and Refrigeration, Nanjing University of Aeronautics and Astronautics, 29 Yudao Street, Nanjing 210016, China

[b] 650 Research Institute, AVIC HONGDU Aviation Industry Group LTD, Nanchang, Jiangxi 330024, China

ARTICLE INFO

Article history:
Received 28 December 2014
Received in revised form 7 July 2015
Accepted 13 July 2015
Available online 17 July 2015

Keywords:
Flow condensation
Heat transfer coefficient
Correlation
Two-phase

ABSTRACT

Condensation heat transfer in tubes is extensively used in many industrial sectors. There were a number of investigations evaluating the correlations of condensation heat transfer in tubes. However, either the data used or correlations involved were limited, resulting in inconsistent conclusions. This paper presents a comprehensive review of correlations for flow condensation heat transfer in horizontal channels. A database containing 2563 experimental data points of condensation heat transfer in horizontal channels, including 1462 data points from conventional channels and 1101 from minichannels, is compiled from 26 published papers, with which 28 correlations are evaluated and analyzed. Twelve correlations have the mean absolute deviation (MAD) less than 30% against the database, and eight have 30% ≤ MAD < 40%. The MADs of the best predictions for the entire database, conventional channel data, and microchannel data are 17.0%, 14.4%, and 20.6%, respectively, indicating a need to improve the prediction method for microchannels.

Corrélations de transfert de chaleur par condensation en écoulement dans des canaux horizontaux

Mots clés : Condensation en écoulement ; Coefficient de transfert de chaleur ; Corrélation ; Diphasique

1. Introduction

Condensation in tubes has many applications, such as refrigeration, air conditioning, electric power generation, and spacecraft thermal control systems. The determination of condensation heat transfer coefficient is important for design, development, and assessment of the systems and equipment. Condensation heat transfer coefficient is affected by various parameters, such as refrigerant properties, tube

* Corresponding author. Institute of Air Conditioning and Refrigeration, Nanjing University of Aeronautics and Astronautics, 29 Yudao Street, Nanjing 210016, China. Tel.: +86 25 84896381; Fax: +86 25 84896381.

E-mail address: xd_fang@nuaa.edu.cn (X. Fang).

http://dx.doi.org/10.1016/j.ijrefrig.2015.07.013

Nomenclature

A	tube cross-sectional area (m^2)
Bd	Bond number
c_p	specific heat at constant pressure (kJ kg^{-1} K^{-1})
D	tube diameter (mm)
Fr	Froude number
G	mass flux (kg m^{-2} s^{-1})
g	gravitational acceleration (m s^{-2})
Ga	Galileo number
Gr	Grashof number
H	latent heat (kJ kg^{-1})
h	heat transfer coefficient (kW m^{-2} K^{-1})
J	dimensionless superficial velocity
Ja	Jakob number
L	length of tube (mm)
Nu	Nusselt number
p	pressure (MPa)
Pr	Prandtl number
q	heat flux (kW m^{-2})
Re	Reynolds number
Su	Suratman number
T	temperature (K, °C)
We	Weber number
X	Lockhart–Martinelli parameter
x	vapor quality

Greek symbols

α	void fraction
Δ	increment
δ	percentage of MRD within ±20%
θ	angle (rad)
λ	thermal conductivity (W m^{-1} K^{-1})
μ	dynamic viscosity (Pa s^{-1})
ν	kinematic viscosity (m^2 s^{-1})
ξ	percentage of MRD within ±30%
ρ	density (kg m^{-3})
σ	surface tension (N m^{-1})
Φ	two-phase multiplier

Subscripts

an	annular flow
bot	bottom
crit	critical
exp	experimental
L	liquid
LO	liquid-only
LV	liquid convert to vapor phase
k	liquid or vapor phase
pred	predicted
rd	reduced
sat	saturation
slug	slug flow
strat	stratified flow
trans	transition
top	top
V	vapor
VO	vapor-only
w	wall
wavy	wavy flow

diameter, saturation temperature, heat flux, mass flux, and vapor quality (Cheng et al., 2007; Fang et al., 2013; Harirchian and Garimella, 2010; Kandlikar and Grande, 2003; Kew and Cornwell, 1997; Li et al., 2010; Mehendale et al., 2000).

The channel dimension has important effects on two-phase flow heat transfer, which has been proved in a number of studies. There are three influential approaches describing the channel transition of two-phase flow (Fang et al., 2013), which are the channel size method (Mehendale et al., 2000; Kandlikar and Grande, 2003), the Bd-type method (Kew and Cornwell, 1997; Cheng et al., 2007), and the multi-dimensionless parameter method (Li et al., 2010; Harirchian and Garimella, 2010). In this paper, the well-known Kandlikar and Grande (2003) method is adopted, which defines $D \geq 3$ mm as conventional channels, 200 μm $\leq D <$ 3 mm as minichannels, and 10 μm $< D <$ 200 μm as microchannels.

For conventional channels, Dobson et al. (Dobson and Chato, 1998; Dobson et al., 1993, 1994) investigated the heat transfer coefficients of R12, R22, R134a, and near-azeotropic blends of R32/R125 in 50%/50% and 60%/40% compositions. Several correlations were suggested for gravity-dominated and shear-dominated flows, and successfully predicted data from their study and several other sources.

Haraguchi et al. (1994) studied experimentally the heat transfer coefficients of R22, R134a, and R123 condensing in an 8.4 mm inner diameter (ID) tube, with mass flux from 90 to 400 kg m^{-2} s^{-1} and heat flux from 3 to 33 kW m^{-2}. An empirical equation based on the turbulent liquid film theory and Nusselt's theory was proposed, which correlated the experimental data with an error of 20%.

Thome et al. (2003) proposed a flow pattern based model of condensation heat transfer in horizontal tubes to predict the experimental database for different flow regimes. The database contained 4621 date points from 15 fluids over the range of mass flux from 24 to 1022 kg m^{-2} s^{-1}, vapor quality from 0.03 to 0.97, reduced pressure from 0.02 to 0.8 MPa, and tube ID from 3.1 to 21.4 mm. The model predicted 85% of the non-hydrocarbon data (1850 data points) and 75% of the hydrocarbon data (2771 data points) within ±20%.

Cavallini et al. (2006) suggested a model for condensation heat transfer coefficient in horizontal tubes, which included a criterion for the transition between two different flow categories, depending on whether the heat transfer coefficient was dependent or independent on the temperature difference ΔT. The model predicted the database containing 4471 data points from the media including HCFCs, HFCs, HCs, carbon dioxide, ammonia, and water with an MAD of 15%.

As for the minichannels, Park and Hrnjak (2009) investigated CO_2 flow condensation heat transfer, pressure drop and flow pattern in 0.89 mm multi-port microchannels at saturation temperatures of −15 and −25 °C, mass flux from 200 to 800 kg m^{-2} s^{-1}, and wall subcooling temperature from 2 to 4 °C.