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Comprehensive correlations for heat transfer during condensation in conventional and mini/micro channels in all orientations

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ABSTRACT

Two alternative correlations are presented for heat transfer during condensation in plain conventional channels as well as mini/micro channels in all orientations. These have been validated by comparison with a database that includes 33 fluids, diameters 0.10 to 49.0 mm, reduced pressures 0.0008 to 0.946, mass flux from 1.1 to 1400 kgm^{-2}s^{-1}, various shapes (round, rectangular, triangular, etc.), all orientations (horizontal, vertical up and down, and angles in between). The data are from 136 data sets from 67 sources. While both correlations predict the 4063 data points with mean absolute deviation (MAD) of about 17%, their accuracy varies somewhat in different ranges. The same data are also compared to other correlations.

Corrélations complètes pour le transfert de chaleur en condensation dans des canaux classiques et des mini/micro canaux dans toutes les orientations

Mots clés : Condensation ; Transfert de chaleur ; Minicanaux ; Macro-canaux ; Corrélation

1. Introduction

Condensers have been in use for more than two centuries. Their applications have included power plants, air conditioning and refrigeration, chemical processes, etc. Until fairly recently, most condensers were constructed of tubes with comparatively large diameters. In recent years, there has been great interest in the use of channels of small diameters as they result in more compact and cost effective designs. Another benefit is that they

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Nomenclature

Bo	Bond number = $g(\rho_L - \rho_G)D^2\sigma^{-1}$ [–]
CHF	critical heat flux [kWm^{-2}]
D	inside diameter of tube [m]
D_{HP}	equivalent diameter based on perimeter with heat transfer, defined by Eq. (18) [m]
D_{HYD}	hydraulic equivalent diameter, defined by Eq. (17) [m]
g	acceleration due to gravity [m s^{-2}]
G	total mass flux (liquid + vapor) [kg $m^{-2}s^{-1}$]
h	heat transfer coefficient [W m^{-2} C^{-1}]
h_I	heat transfer coefficient given by Eq. (1) [W m^{-2} C^{-1}]
h_{LO}	heat transfer coefficient assuming liquid phase flowing alone in the tube [Wm^{-2} C^{-1}]
h_{LT}	heat transfer coefficient with total mass flowing as liquid [W m^{-2} C^{-1}]
h_{Nu}	heat transfer coefficient given by Eq. (2), the Nusselt equation [W m^{-2} C^{-1}]
h_{TP}	two-phase heat transfer coefficient [W m^{-2} C^{-1}]
$h_{TP,\theta}$	two-phase heat transfer coefficient at tube inclination θ [Wm^{-2} C^{-1}]
J_g	dimensionless vapor velocity defined by Eq. (10)
k	thermal conductivity [W m^{-1} C^{-1}]
MAD	mean absolute deviation
N	number of data points
Pr	Prandtl number [–]
p_r	reduced pressure [–]
Re_{GT}	Reynolds number for all mass flowing as vapor = $GD\mu_G^{-1}$ [–]
Re_{LO}	Reynolds number assuming liquid phase flowing alone, = $G(1 - x)D\mu_L^{-1}$ [–]
Re_{LT}	Reynolds number for all mass flowing as liquid = $GD\mu_L^{-1}$ [–]
T_{SAT}	saturation temperature [C]
T_w	wall temperature [C]
We_{GT}	Weber number for all mass flowing as vapor, defined by Eq. (13) [–]
x	vapor quality [–]
Z	Shah's correlating parameter defined by Eq. (7) [–]
ΔT	= $(T_w - T_{SAT})$ [degree C]

Greek

Σ	mathematical symbol for summation
δ_{avg}	average deviation, defined by Eq. (29) [–]
δ_m	mean absolute deviation, defined by Eq. (27) [–]
θ	inclination of tube to horizontal [degree (–90° is vertical downflow, +90° is vertical upflow, 0° is horizontal)]
μ	dynamic viscosity [Pa · s]
ρ	density [kg m^{-3}]

Subscripts

G	vapor
L	liquid

reduce the amount of refrigerant in refrigeration systems and thus reduce environmental impact in case of leakage. While most condensers involve horizontal or vertical downward flow, some applications involve other orientations, for example air cooled condensers for power plants. Hence methods for predicting heat transfer are needed for conventional tube sizes as well as mini/micro channels, and in all orientations. Numerous correlations have been proposed for heat transfer in channels of conventional sizes though only a few have been validated with data covering a wide range. Among such correlations are those of Cavallini et al. (2006), Thome et al. (2003), and Shah (2009, 2013). Numerous correlations have also been proposed for mini/micro channels but only two of those have been validated with wide ranging data from many sources; these are the ones by Kim and Mudawar (2013) and Shah (2016b). For inclined tubes, the only well-validated correlation is by Shah (2016a). While there are these separate correlations for conventional channels, mini/micro channels, and inclined channels, there is no comprehensive correlation applicable to all channel types and inclinations. The author therefore made an effort to develop such a comprehensive correlation. This effort has resulted in the development of two well-verified comprehensive correlations.

In the following, the previous research in this field is reviewed, the development of the new correlations is described, and their comparison with an extensive database is presented. These data include 33 fluids (water, CO_2, methane, new and old halocarbon refrigerants, hydrocarbons), diameters of