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A generalized dimensionless local power-law correlation for refrigerant flow through adiabatic capillary tubes and short tube orifices

Liang Yang, Chun-Lu Zhang *

School of Mechanical Engineering, Tongji University, Shanghai 201804, China

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ABSTRACT

This paper presents a new method to obtain generalized dimensionless correlation of refrigerant mass flow rates through adiabatic capillary tubes and short tube orifices. The dimensionless Pi groups were derived from the homogeneous equilibrium model, which is available for different refrigerants entering adiabatic capillary tubes or short tube orifices as the subcooled liquid, two-phase mixture, or supercritical fluid. To mitigate the potential over-fitting risk in neural network, a new "local" power-law correlation reformed from the homogeneous equilibrium model was proposed and compared with the conventional "global" power-law correlation and recently developed neural network model. About 2000 sets of experimental mass flow rate data of R12, R22, R134a, R404A, R407C, R410A, R600a and CO_2 (R744) in the open literature covering capillary and short tube geometries, subcritical and supercritical inlet conditions were collected for the model development. The comparison between the recommended six-coefficient correlation and experimental data reports 0.80% average and 8.98% standard deviations, which is comparable with the previously developed neural network and much better than the "global" power-law correlation.

Une corrélation locale adimensionnelle généralisée de loi de puissance pour l'écoulement du frigorigène dans des tubes capillaires et des orifices de tubes courts

Mots clés : Frigorigène ; Vitesse d'écoulement ; Capillaire ; Orifice ; Corrélation

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* *Corresponding author*. Tel.: +86 136 71825 133.
E-mail address: chunlu.zhang@gmail.com (C.-L. Zhang).

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Nomenclature

a_i	empirical coefficients in correlations
c_p	specific heat at constant pressure (J kg^{-1} K^{-1})
D	tube diameter (m)
f	friction factor
G	mass flux (kg m^{-2} s^{-1})
L	tube length (m)
N	number of data
m	mass flow rate (kg s^{-1})
p	pressure (Pa)
T	temperature (°C)
v	specific volume (m^3 kg^{-1})

Greek symbols

μ	viscosity (N s m^{-2})
π_i	dimensionless Pi groups
ρ	density (kg m^{-3})

Superscripts and Subscripts

f	saturated liquid at the inlet saturation pressure
g	saturated vapor at the inlet saturation pressure
in	inlet
m	mean value
max	maximum
sat	saturation

1. Introduction

Capillary tubes and short tube orifices are widely used as the throttling and flow-rate controlling device on the residential and light commercial air conditioning, refrigeration and heat pump units because of the simple configuration, high reliability, and low cost. On the other hand, the complexity of critical two-phase flow inside the tube and the substitution of conventional CFC and HCFC refrigerants brought plenty of theoretical and experimental investigations on capillary tubes and short tube orifices since 1940's (ASHRAE, 2010; Khan et al., 2009; Nilpueng and Wongwises, 2012a, b).

For ease-of-use in engineering applications and for fast and robust computation in system modeling, empirical or semi-empirical models or correlations of refrigerant mass flow rate through capillary tubes or short tube orifices have been developed. Particularly, since Bittle et al. (1998) proposed a generalized power-law correlation for adiabatic capillary tubes based on the dimensional analysis, this type of correlations has been applied to different refrigerants or data banks by many researchers (ASHRAE, 2010; Choi et al., 2004; Choi et al., 2003; Yang and Wang, 2008). On the other hand, to overcome the numerical issues in the existing power-law correlations and improve the model accuracy, Zhang (2005) first developed a new type of capillary tube model using artificial neural network (ANN). Then the neural network model was modified with new dimensionless Pi groups based on the homogeneous equilibrium model (HEM) (Zhang and Zhao, 2007) and was extended to short tube orifices (Zhao et al., 2007) and transcritical CO_2 throttling device (Yang and Zhang, 2009). In addition, Vinš and Vacek (2009) applied the neural network to a new refrigerant R218 and Heimel et al. (2014) extended it to non-adiabatic capillary tubes. Shao et al. (2013) did a comprehensive assessment on the existing dimensionless correlations and neural networks of adiabatic capillary tubes and found there is still room for improvement in model generality and over-fitting risk mitigation.

In this work, we propose a generalized "local" power-law correlation model based on the HEM for supercritical, subcooled or two-phase refrigerant flowing through adiabatic capillary tube or short tube orifice. About 2000 sets of experimental data in the open literature including refrigerants R12, R22, R134a, R404A, R407C, R410A, R600a and CO_2 (R744) are collected for data regression and comparison with the conventional power-law correlation and neural network model. It turns out the new local power-law correlation is much more accurate than the conventional power-law correlation model and no over-fitting risk in comparison with the neural network model.

2. Dimensionless parameter groups

In terms of the recent assessment (Shao et al., 2013), the dimensionless parameter groups derived from the HEM (Yang and Zhang, 2009) are more effective than those from the conventional dimensional analysis method (Bittle et al., 1998; Choi et al., 2003). Therefore, we keep using the dimensionless Pi groups developed by Yang and Zhang (2009). To give a

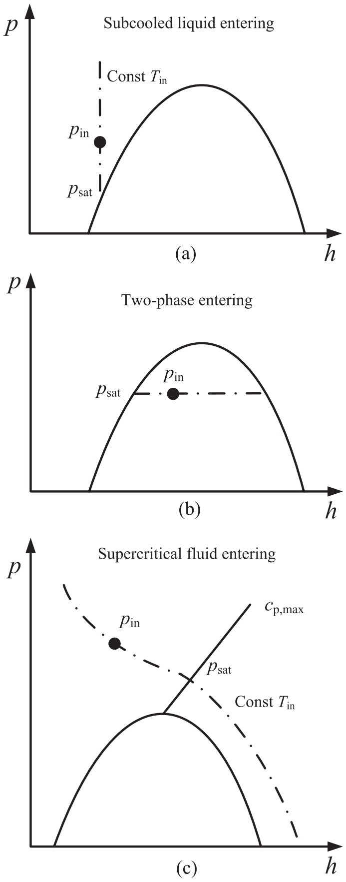

Fig. 1 – Definition of p_{sat} under different inlet conditions