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Comparison and development of new correlation for adiabatic two-phase pressure drop of refrigerant flowing inside a multiport minichannel with and without fins

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ABSTRACT

This study examines the experimental adiabatic two-phase frictional pressure drop of R134a in rectangular multiport minichannel with and without fins having 20 channels with hydraulic diameters of 0.64 mm and 0.81 mm, respectively. The pressure drop measurements were done under mass flux range of 50–200 kg m^{-2} s^{-1}, saturation temperature range of 20–35 °C, and inlet vapor quality range of 0.1–0.9. The effects of mass flux, saturation temperature, inlet vapor quality and channel geometry on frictional pressure drop were investigated. The results discovered that the mass flux, inlet vapor quality, saturation temperature and channel geometry play an important role in increasing or decreasing the frictional pressure drop. The present experimental data were compared with eleven existing well known frictional pressure drop correlation available in the open literature. In addition, a new two-phase frictional pressure drop correlation is proposed considering the effects of inertia, viscous force, fluid properties, channel geometry and surface tension and also validated the correlation with the available data.

Comparaison et développement d'une nouvelle corrélation pour la chute de pression diphasique adiabatique du frigorigène circulant à l'intérieur d'un minicanal multi-port avec et sans ailettes

Mots clés : Adiabatique ; Chute de pression frictionnelle ; Minicanal multi-port ; Corrélation ; Écoulement diphasique ; Multiplicateur diphasique

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Nomenclature

Bo	Bond number
d	diameter [m]
Fr	Froude number
f	friction factor
G	mass flux [kg m^{-2} s^{-1}]
g	gravitational acceleration [m s^{-2}]
h	enthalpy [J kg^{-1}]
N_{conf}	confinement number
P	pressure [Pa]
ΔP	pressure drop [Pa]
Δz	measuring length [m]
Re	Reynolds number
Su	Suratman number
T	temperature [°C]
v	specific volume [m^3 kg^{-1}]
Δv	specific volume difference between saturated vapor and saturated liquid [m^3 kg^{-1}]
We	Weber number
x	vapor quality

Greek symbols

Φ	two-phase frictional multiplier
λ	channel geometry constant
β	aspect ratio
ρ	density [kg m^{-3}]
μ	viscosity [Pa·s]
ν	kinetic viscosity [m^2 s^{-1}]
σ	surface tension [N m^{-1}]
X	Lockhart–Martinelli parameter

Subscripts

F	friction
tp	two-phase
c	abrupt contraction
e	abrupt expansion
$pred$	predicted
exp	experimental
cr	critical
lo	liquid phase with total flow
vo	vapor phase with total flow
h	hydraulic diameter
T	total
ref	refrigerant
sat	saturation
in	inlet
out	outlet
l	saturated liquid
v	saturated vapor
tt	turbulent liquid–turbulent vapor
tl	turbulent liquid–laminar vapor
lt	laminar liquid–turbulent vapor
ll	laminar liquid–laminar vapor

1. Introduction

Minichannels are increasingly being used for the fabrication of compact and high performance heat exchanger in refrigeration, air condition, automotive, some industrial and heat pump systems for a wide variety of applications to improve the performance of that system. There are many advantages of using minichannels such as higher heat transfer, reduced weight, reduced air side pressure drop and substantial refrigerant charge reduction as well as their space, energy, and material savings potential when compared to conventional tube heat exchangers for the same capacity. The charge reduction is very important in recent heat pumping equipment and refrigeration systems to enhance the safety measure of flammable refrigerant and meet the environmental concerns of using high global warming potential (GWP) refrigerant. Recently, several researchers found that the heat transfer is significantly empowered by reducing the channel diameter. Despite those advantages, unfortunately, a higher pressure drop is obtained, which may degrade the overall efficiency of the two-phase system (Kim and Mudawar, 2012; Lopez-Belchi et al., 2014). Although two-phase frictional pressure drop has been a research subject for several decades and many researchers extensively investigated the two-phase pressure drop characteristics in minichannels experimentally and theoretically, the information on two-phase pressure drop is still inadequate. Hence, the design of high performance minichannel heat exchanger essentially requires accurate predictive tools for pressure drop prediction in two-phase flow.

Adiabatic and diabatic two-phase pressure drop can be predicted based on either the homogeneous model or the separated flow model. The simplest approach to the prediction of two-phase flows is homogeneous model, which assumes that the phases are thoroughly mixed and can be treated as a single-phase flow. However, the homogeneous method is not suitable for mass flux less than 2000 kg m^{-2} s^{-1} and at low reduced pressure (Thome, 2006), whereas in separated flow model the phase is considered to be flowing separately. The frictional pressure drop in two-phase flows is typically predicted using separated flow models. The first separated flow model was proposed for isothermal two-phase flow pressure drop by Lockhart and Martinelli (1949) and then followed by many others. Chisholm (1967) developed a theoretical basis for the Lockhart–Martinelli correlation for two-phase flow. Later on, Friedel (1979), Müller-Steinhagen and Heck (1986), Jung and Radermacher (1989), and Wang et al. (1997) proposed a simple model for two-phase frictional pressure drop prediction in macro-channels. Among them, Friedel (1979) and Müller-Steinhagen and Heck (1986) correlations were developed using a large data bank containing 25,000 and 9300 measurements of frictional pressure drop for a variety of fluids and conditions respectively. Those models are widely used in conventional theory to predict frictional pressure drop in macro-channels; many recent authors (Choi et al., 2008; Xu et al., 2012) have reported the ability of these correlations to estimate with reasonable accuracy of the frictional pressure drop in mini-channels (Lopez-Belchi et al., 2014).

In the recent past, much experimental research was devoted to measuring the frictional pressure drop during two-phase flow in small diameter tubes and in minichannels of circular or