Applied Thermal Engineering 127 (2017) 547–558

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Development of a continuous empirical correlation for refrigerant mass flow rate through non-adiabatic capillary tubes

Mehdi Rasti, Jeong Ho Ban, Ji Hwan Jeong *

School of Mechanical Engineering, Pusan National University, Geumjeong-Gu, Busan 46241, Republic of Korea

HIGHLIGHTS

- Continuous correlation for mass flow rate through non-adiabatic capillary tube.
- Single correlation is applicable to subcooled, two-phase, and superheated regions.
- Correlation was validated to be applicable to R-134a, R-410A, R-152a, and R-22.

ARTICLE INFO

Article history:
Received 26 January 2017
Revised 5 July 2017
Accepted 12 August 2017
Available online 14 August 2017

Keywords:
Refrigerant
Non-adiabatic capillary tube
Mass flow rate correlation
Continuous capillary model
Dimensionless parameter
Buckingham theorem

ABSTRACT

Capillary tube, suction line heat exchangers (CT-SLHX) are widely used as expansion devices in small-capacity refrigeration and air-conditioning systems to enhance the refrigeration capacity and ensure that superheated refrigerant vapor enters the compressor. To calculate the mass flow rate through a capillary tube, a reliable non-adiabatic capillary tube model is necessary. Most previous correlations were developed separately for subcooled liquid inlet conditions and for saturated two-phase inlet conditions; so the models are not continuous at the saturated liquid point. An empirical model that is continuous at the saturated liquid point was developed and is introduced herein with a new dimensionless π parameter. This new empirical model is validated using experimental measurements available in the literature for the refrigerants R-134a, R-600a, R-410A, R-152a, and R-22. The new correlation shows good agreement with the experimental data.

1. Introduction

A throttling device connects the condenser outlet to the evaporator inlet, causes a drop in refrigerant pressure, and regulates the refrigerant mass flow rate. A capillary tube is widely used as the throttling device in small-capacity vapor-compression refrigeration systems such as household refrigerators and freezers. It has some advantages including simplicity, low cost, no moving parts, and reduction of the compressor starting torque due to equalization of the condenser and evaporator pressures during the off-cycle [1]. A capillary tube is a long and narrow hollow copper tube with a constant cross-sectional area. Generally, the capillary tube inner diameter and its length varies from 0.33 mm to 2.0 mm, and 2 m to 6 m, respectively [2]. Although a capillary tube appears to be quite simple, the refrigerant flow inside the capillary tube is rather complicated because the refrigerant experiences various thermodynamic states including subcooled liquid, meta-stable liquid, meta-stable two-phase, and saturated two-phase.

Generally, capillary tubes can be categorized as straight or coiled depending on their geometry, and as adiabatic or non-adiabatic depending on the intentional heat transfer to a suction line [3,4]. An adiabatic straight capillary is thermally insulated with negligible heat exchange with the ambient environment. Fig. 1 illustrates a schematic and a P-h diagram of a vapor compression refrigeration system with an adiabatic capillary tube in which the refrigerant is subject to an isenthalpic process. The point 3 in Fig. 1(b) represents that the refrigerant enters the adiabatic capillary tube in a subcooled liquid state. Process 3-4 in Fig. 1(b) is adiabatic and the refrigerant temperature remains constant as far as it is in the subcooled liquid state. Due to flashing of the saturated liquid, a part of total energy converts into kinetic energy. As a result, the enthalpy of refrigerant slightly falls in the latter part of the adiabatic capillary tube.

Fig. 2 shows a schematic and a P-h diagram of a vapor compression refrigeration system with a non-adiabatic capillary tube. The non-adiabatic capillary tube is soldered onto the suction line

---

* Corresponding author.
E-mail address: jihwan@pusan.ac.kr (J.H. Jeong).

http://dx.doi.org/10.1016/j.applthermaleng.2017.08.070

Nomenclature

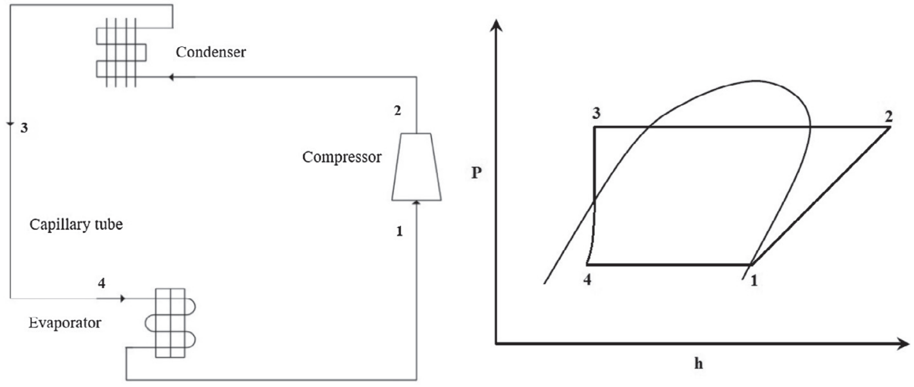
A	area, m^2
C	specific heat, J kg^{-1} K^{-1}
D	diameter, m
f	friction factor
h	enthalpy, J kg^{-1}
HX	heat exchanger
L	length, m
Nu	Nusselt number
$\dot{m}$	mass flow rate, kg s^{-1}
P	pressure, Pa
Pr	Prandtl number
Re	Reynolds number
T	temperature, K
V	velocity, m/s
x	vapor quality
y	meta-stable mass fraction
z	section length, m

Greeks

λ	thermal conductivity, W m^{-1} K^{-1}
μ	viscosity, kg m^{-1} K^{-1}
π	pi dimensionless parameter
ρ	density, kg m^{-3}
v	specific volume, m^3 kg^{-1}
σ	surface tension, N m^{-1}
ε	wall roughness, mm
φ^2	frictional two-phase multiplier

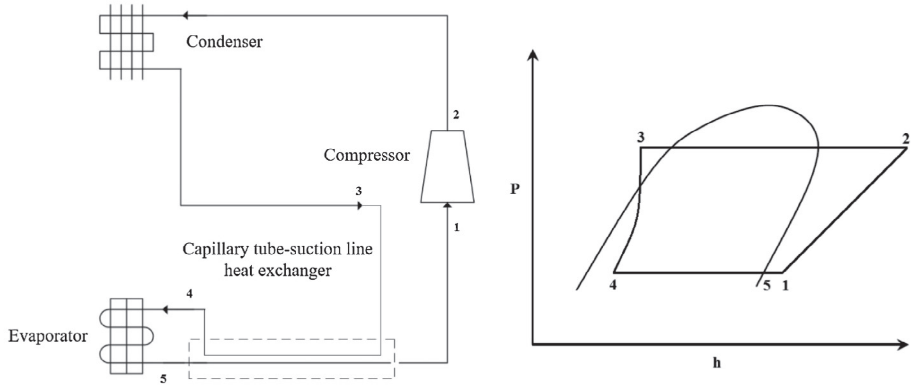
Subscripts

c	capillary tube
$crit$	critical
$cond$	condensing
f	saturated liquid
g	saturated vapor
hx	heat exchanger
in	inlet
l	liquid
lo	liquid only
p	constant pressure
out	outlet
s	suction line
sat	saturated
sc	capillary tube inlet subcooled level
seg	segment
sh	suction line inlet superheat level
sp	single phase
sup	superheat
tp	two-phase
v	vapor



(a) Refrigeration system (b) P-h diagram

Fig. 1. Vapor compression system employing adiabatic capillary tube.



(a) Refrigeration system (b) P-h diagram

Fig. 2. Vapor compression system employing capillary tube suction line heat exchanger.