International Communications in Heat and Mass Transfer 93 (2018) 21–33

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Investigation of boiling heat transfer characteristics of R134a flowing in smooth and microfin tubes

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ARTICLE INFO

Keywords:
Microfin tube
Boiling heat transfer coefficient
Pressure drop
Heat transfer enhancement

ABSTRACT

In this study, boiling heat transfer and pressure drop experiments are performed in order to investigate heat transfer enhancement of microfin tube comparing with smooth one. During constant heat flux (10 kW m^{-2}) experiments, effect of mass flux (190–381 kg m^{-2} s^{-1}), saturation temperature (15–22 °C) and vapor quality (0.21–0.77) on heat transfer coefficient and pressure drop are investigated. In addition, boiling heat transfer coefficient and frictional pressure drop correlations given in the literature are compared with measured ones. Moreover, the experiments revealed that experimental boiling heat transfer coefficient and total pressure drop of R134a flowing microfin tube are 1.9 and 3.0 times higher than smooth one having the same fin root diameter, respectively. Furthermore, 94 number of heat transfer and pressure drop raw experimental data belonging to the microfin tube are given for researchers to validate their theoretical models.

1. Introduction

Evaporators and condensers are generally used in air conditioning, refrigeration and heat pump applications. In order to improve tube side performance of these heat exchangers, microfin tubes can be used instead of smooth ones because of their heat transfer enhancement and small pressure drop increment characteristics. Microfin tubes generally consists of 50–70 small fins located helically along the tube and having height lower than 0.4 mm. The experimental studies on flow boiling heat transfer and pressure drop of refrigerants in microfin tubes are given as follows:

Kim and Shin [1] conducted an experimental study to investigate the evaporative heat transfer of R22 and R410A in a smooth and seven different microfin tubes. Microfin tube geometry consisted of five single-grooved and two cross-grooved fin profiles. Nearly all experimental data are taken in annular flow conditions. Heat transfer of single-grooved tubes are found to be superior to the cross-grooved tubes except for one case. The microfin tube with the largest heat transfer area is found to have the best heat transfer results. Experiments also revealed that the heat transfer for R410A is higher than R22 for nearly all of the experimental configurations.

Seo and Kim [2] studied the heat transfer and pressure drop of R22 using two different smooth and microfin tubes. In both smooth and microfin tubes, increase of mass flux and decrease of evaporation temperature result in increasing heat transfer coefficient however, increase of heat flux lowered heat transfer coefficient in microfin tubes while opposite situation observed in smooth tubes. Enhancement factor microfin tube is also found to be more significant in higher diameter tubes.

Chamra et al. [3] experimentally investigated the pressure drop and heat transfer for four different microfin tube types with various different geometrical properties using R22 refrigerant. Cross-grooved microfin geometry is found to have superior heat transfer than the other helical microfin tubes. Helix angle of 20° is also found to have the higher heat transfer coefficient for all of the configurations.

Kondou et al. [4] studied the heat transfer and pressure drop in flow

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https://doi.org/10.1016/j.icheatmasstransfer.2018.03.006

Nomenclature

A_s	heat transfer area, m^2
A_c	cross section area, m^2
b	distance between fin roots, mm
c	distance between fin tips, mm
d	fin root length, mm
Bo	Boiling number
c_p	specific heat, $J\,kg^{-1}\,K^{-1}$
D_b	departure bubble diameter, m
D_i	Inside diameter of tube, m
D_o	Outside diameter of tube, m
D_h	Hydraulic diameter of tube, m
e	fin height, mm
f	friction factor
G	mass flux of R134a, $kg\,m^{-2}\,s^{-1}$
h_{exp}	experimental (average) convective heat transfer coefficient, $W\,m^{-2}\,K^{-1}$
h_i	local convective heat transfer coefficient, $W\,m^{-2}\,K^{-1}$
h_{fg}	latent heat of vaporization of R134a, $kJ\,kg^{-1}$
I	current, A
k	thermal conductivity, $W\,m^{-1}\,K^{-1}$
L	test section length, m
M	molecular weight, $kg\,kmol^{-1}$
$\dot{m}$	mass flow rate, $kg\,s^{-1}$
n	number of measuring sections
P	pressure, Pa
Pr	Prandtl number
q''	heat flux, $W\,m^{-2}$
Re	Reynolds number
S	perimeter of one fin and channel taken perpendicular to the axis of the fin, mm
T	temperature, °C
T_b	bubble point temperature of mixture, °C
T_d	dew point temperature of mixture, °C
T_s	saturated state temperature of mixture, °C
t	tube wall thickness, mm
$\dot{Q}_{PS}$	heat obtained by power supply, W
x	vapor quality
V	Voltage, V
w	fin tip length, mm
X_{tt}	Lockhartt–Martinelli parameter
z	distance from inlet, m
β	helix angle, (°)
θ	fin angle, (°)
ϕ	two-phase multiplier
ρ	density, $kg\,m^{-3}$
μ	dynamic viscosity, $kg\,m^{-1}\,s^{-1}$
σ	surface tension, $N\,m^{-1}$
δ	film thickness, m
α	void fraction

Subscripts

acc	acceleration
avg	average
c	critical condition
cb	convective boiling
f	friction factor
i	inlet
l	liquid
lo	liquid only
LV	least volatile component
MV	more volatile component
nb	nucleate boiling
pb	pool boiling
ONB	onset of nucleate boiling
r	reduced
o	outlet
s	surface
st	static
t	total
v	vapor
vo	vapor only
TS	test section

boiling of R32/R1234ze(E) mixture in a single microfin tube. The heat transfer for the mixture is found to be lower than the components of the mixture due to the volatility difference of the individual components. The lowest heat transfer result obtained at the 0.2/0.8 mass composition. Authors also developed a prediction method for heat transfer coefficient. Pressure drop equations for single-component refrigerants also showed acceptable results for the mixture when mixture properties are used in the calculations.

Table 1
Details of experimental conditions.

Saturation temperature (°C)	Mass flux ($kg\,m^{-2}\,s^{-1}$)	Heat flux ($kW\,m^{-2}$)	Vapor quality (−)
15	190	10	0.32–0.71
15	290	10	0.32–0.70
15	381	10	0.22–0.57
22	190	10	0.25–0.77
22	290	10	0.31–0.76
22	381	10	0.21–0.65

Spindler and Müller-Steinhagen [5] used a single microfin tube to experimentally study the heat transfer in flow boiling of R134a and R404A refrigerants. Experiments conducted under stratified, stratified-wavy, intermittent and annular flow regimes. R134a showed higher heat transfer performance than the R404A at the same experimental saturation pressures.

Filho et al. [6] experimentally studied the pressure drop of R134a in three smooth and microfin tubes. Most of the experiments are conducted under annular flow regime. A Martinelli type equation is developed to predict the frictional pressure drop for microfin tubes and showed good agreement with the data in the study and the data from the literature. It is also concluded that the fin number and geometry have no effect on the pressure drop.

Yu et al. [7] experimentally investigated the flow pattern distribution and heat transfer coefficient of R134a boiling in smooth and microfin tubes. Wavy, intermittent, semi-annular and annular flow regimes are observed during experiments. Flow pattern transition for microfin tube is found to be happen in lower mass flux and quality values than smooth tube due to grooves in the microfin geometry. Maximum heat transfer enhancement of 200% is calculated under annular flow regime in microfin tubes. Gungor and Winterton correlation