International Journal of Heat and Mass Transfer 117 (2018) 924–939

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Effect of straight micro fins on heat transfer and pressure drop of R410A during evaporation in round tubes

Cheng-Min Yang [a], Pega Hrnjak [a,b,*]

[a] Air Conditioning and Refrigeration Center, Department of Mechanical Engineering and Science, University of Illinois at Urbana-Champaign, 1206 W Green St, Urbana, IL, USA
[b] CTS-Creative Thermal Solutions, 2209 Willow Rd, Urbana, IL, USA

ARTICLE INFO

Article history:
Received 26 August 2017
Received in revised form 16 October 2017
Accepted 16 October 2017
Available online 23 October 2017

Keywords:
Axial micro-finned tube
Straight micro fin
Evaporation
R410A
HTC
Pressure drop

ABSTRACT

The objective of this paper is to present the influence of straight micro-fins on heat transfer coefficient and pressure drop. R410A flow boiling experiments were conducted in both smooth tube and the axial micro-finned tube. Data are taken at 10 °C saturation temperature for the vapor quality from 0.1 to 0.9, mass flux from 100 to 450 kg/s-m^2, and heat flux from 10 to 20 kW/m^2. The results in the smooth tube were compared with several correlations and used as a baseline. It was observed that straight micro-fin structure played an important role in the evaporative heat transfer. The heat transfer coefficient was significantly enhanced in the axial micro-finned tube, whose enhancement factor ranged from 1.03 to 1.48 with average of 1.34. As the mass flux and vapor quality was low, the straight micro-fins had stronger influence of the heat transfer coefficient since the liquid-phase refrigerant was easily trapped in the grooves of the axial micro-finned tube. The pressure drop penalty factor of the axial micro-finned tube ranged from 0.66 to 1.6, and the average was around 1.23.

1. Introduction

Internally micro-finned tubes, first developed in 1977 by Hitachi Cable [1], have received increasing attention and are commonly used in air conditioners and refrigerators as evaporator and condenser tubes. It is generally known that the inner micro-fin provides more heat transfer area, and increases wetting of the tube, which are believed to increase heat transfer performance in two-phase flow. A number of experimental studies on evaporation in micro-finned tubes have been reported. Seo and Kim [2] measured the evaporation heat transfer coefficients and pressure drop of R410A in 7.0 and 9.52 mm OD micro-finned tubes. The average *EF* (heat transfer enhancement factors) for 7.0 and 9.52 mm OD micro-fin tubes were 1.1–1.6 and 1.8–2.5 respectively. Zhang et al. [3] experimentally study the flow boiling for R417A in internally grooved tubes and found that heat transfer enhancement factor was 1.26–2.8 and *PF* (pressure drop penalty factor) was 1.8–2.6. Therefore, the micro-fin is seen as an effective geometry to increase in-tube heat transfer rate.

Helix angle is an important parameter in micro-finned tubes, and many studies have shown that it influences the heat transfer coefficient and pressure drop in two-phase flow. In 1979, Ito and Kimura [4] experimentally investigated the boiling heat transfer coefficient and pressure drop in internally spiral-grooved tubes with the helix angle of 0°, 3°, 7°, 15°, 30°, 75° and 90° at various mass fluxes, heat fluxes, and vapor mass qualities. The results showed that the largest value of *HTC* occurs when the helix angle is around 7° and 90°. Schlager et al. [5] studied evaporation and condensation for R22 in horizontal micro-fin tubes with helix angles from 15° to 25°, and the results showed that the 25° helix angle tube had the best performance. Kim and Shin [6] tested performance of different micro-fin tubes in evaporation, and concluded that the heat transfer coefficient decreases with the increase of helix angles.

Recently, aluminum axial micro-finned tubes (0° helix angle) have been considered to replace copper helical micro-finned tubes in the HVAC industry due to the dramatic rise in copper cost and manufacturing cost. Thus, the performance between the helical micro-fin and straight micro-fin in evaporation and condensation are worthy to discuss. Ito and Kimura [4] stated that the longitudinal fin could not enhance the boiling heat transfer effectively compared to the helical fin. In contrast, Wu et al. [7] found that the form drag caused by the helix angle greatly influenced the performance when the tube diameter is small, and the 0° helix angel fins had the potential for enhancing heat transfer in evaporation. Their results showed that the 0° helix micro-fin tubes increase the R32

* Corresponding author at: Air Conditioning and Refrigeration Center, Department of Mechanical Engineering and Science, University of Illinois at Urbana-Champaign, 1206 W Green St, Urbana, IL, USA.

E-mail address: pega@illinois.edu (P. Hrnjak).

https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.064
0017-9310/

Nomenclature

A	area (m^2)
C_P	specific heat (J/kg-K)
D	diameter (m)
EF	enhancement factor
G	mass flux (kg/s-m^2)
HTC	heat transfer coefficient (W/m^2-K)
$\dot{m}$	mass flow rate (kg/s)
n_f	number of micro-fins
P	pressure (Pa)
PF	penalty factor
q	heat flux (W/m^2)
$\dot{Q}$	heat transfer rate (W)
R_q	root-mean-square surface roughness (μm)
T	temperature (°C)
U	expanded relative uncertainty (%)
UA	overall heat transfer coefficient (W/K)
x	vapor quality

Subscripts

amb	ambient
cond	conduction
CS	cross section
evap	evaporation
h	horizontal
i	inlet
melt	melt-down
o	outlet
OD	outer diameter
surf	surface
sat	saturated
v	vertical
w	water

boiling heat transfer by 60% compared with the smooth tubes. However, there is limited research concerned with boiling heat transfer in axial micro-finned tubes, and the mechanism of heat transfer enhancement due to the straight micro-fin is not clear yet. Hence, it is of importance to develop fundamental understanding of the effect of the straight micro-fin on flow boiling.

This study aimed at investigating the heat transfer coefficient and pressure drop during R410A evaporation in a horizontal smooth tube and axial micro-finned tube. Results are compared and discussed in terms of heat flux, mass flux, vapor quality and geometry effects.

2. Experiments

2.1. Test apparatus

Fig. 1 shows a schematic view of the facility. There are two independent loops: one for R410A and the other for water. The R410A loop is composed of a gear pump, mass flow meter, calorimeter, heat transfer test section, visualization section, horizontal pressure section, vertical pressure section, control heater, receiver and subcooler. The gear pump is used to circulate the refrigerant in an oil-free condition. Liquid R410A is pumped to the calorimeter, which is designed for controlling the vapor quality of the heat transfer test section. After the heat transfer test section, a transparent visualization section can be found, which is designed to observe two-phase flow patterns near adiabatic condition. Horizontal and vertical pressure drops are in turn measured by differential pressure transducers near adiabatic condition. Behind the pressure measurement sections, there is a control heater for maintaining a desired saturation temperature in the loop. A plate heat exchanger located at the downstream of the loop enables the refrigerant to condense by exchanging heat with a R404A cooling unit, and a receiver is set at the outlet of the condenser for storing the liquid refrigerant. The water loop consists of a pump, mass flow meter, and a cartridge heater. The cold water is heated by the cartridge heater in order to provide the desired heat flux to the heat transfer test section.

2.2. Heat transfer test section

As illustrated in Fig. 2(a), the heat is transferred to the refrigerant from two half cylinder brass pieces surrounding the aluminum tube assembly. The temperature of the brass pieces is controlled by the water circulating through the brass pieces. The brass pieces provide a uniform temperature distribution to the wall of the aluminum tube assembly by dampening the influence of the water temperature difference between the test section inlet and outlet. All gaps between the two brass pieces and the aluminum tube assembly are filled with high thermal conductivity paste to reduce the thermal contact resistance, and the upper and lower parts of the brass jackets are tightened with two metal band clamps.

The inner aluminum tube is the heat transfer test section 150 mm long with outer diameter of 7.0 mm. Due to the smaller outer diameter of the test section aluminum tube than the brass segments, two half-aluminum jackets are placed around it to form an aluminum tube assembly, shown in Fig. 2(b). Fig. 2(c) and (d) show the longitudinal view of aluminum jacket and the locations of thermocouples, respectively. There are four grooves on each aluminum jacket, designed for placing thermocouple wires. Four thermocouples at top, two sides, and bottom are attached at three locations along the test section. So, twelve thermocouples in total are placed in the grooves and passed through the apertures with the rounding of the corners. In addition, the thermal paste is applied on the thermocouple beads to ensure they contact the inner aluminum tube even closer.

2.3. Geometric shape

Two types of extruded aluminum tubes were used: smooth tube and axial micro-finned tube. Details of geometries including micro-fin structure are summarized in Table 1. The smooth aluminum tube has an outer diameter of 7.0 mm and an inner diameter of 6.3 mm, as shown in Fig. 3(a). The axial micro-finned tube used in this study is special compared to most of the work in the literature. In the real manufacturing process of fin-tube type heat exchanger, the tube expansion technique is widely used to provide a better contact of the micro-finned tubes and external air-side fins. Hwang et al. [8] discussed the copper micro-finned tubes before and after tube expansion, and mentioned that the fin height and outer diameter changed from 0.20 mm to 0.16 mm (decrease of 20%) and 9.52 mm to 10.02 mm (increase of 5.25%) in this expansion process, respectively. In their results, heat transfer coefficient degraded 16.5% after expansion process. Consequently, expansion process in micro-finned tube should be considered especially in aluminum tubes with thicker tube wall.

In order to replicate this process, the OD 7.0 mm axial micro-finned tube without air-side fins was expanded by drawing an