Applied Thermal Engineering 129 (2018) 535–548

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Condensation of R-134a inside dimpled helically coiled tube-in-shell type heat exchanger

Anand Kumar Solanki *, Ravi Kumar

Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee 247667, India

HIGHLIGHTS

- Dimple helically coiled tube gives a higher heat transfer coefficient.
- The effect of mass flux, vapor quality and saturation temperature are considered.
- Flow transitions for dimpled helically coiled tube occurred at lower vapor quality.
- Dimple helically coiled tube yields a higher pressure drop than straight tube.

ARTICLE INFO

Article history:
Received 1 July 2017
Revised 29 September 2017
Accepted 4 October 2017
Available online 12 October 2017

Keywords:
Condensation
Heat transfer coefficient
Frictional pressure drop
R-134a
Dimpled helically coiled tube

ABSTRACT

In this study, condensation heat transfer coefficients and frictional pressure drops of R-134a inside a dimpled helically coiled tube are experimentally investigated. The inner tubes comprise of one smooth straight tube, one smooth helically coiled tube and one dimpled helically coiled tube. The experimental measurements are carried out at saturation temperature of 35°, and 45 °C with mass flux of 75, 115, 156 and 191 kg m^{-2} s^{-1}. The experimental data of a smooth and dimpled helically coiled tube have been plotted on the mass flux versus vapor quality flow map and Tailtel and Dukler flow map. The transitions between different flow regimes have also been discussed. Moreover, the effect of mass flux, vapor quality and saturation temperature of R-134a on the heat transfer coefficients and pressure drops are examined. Comparisons between smooth straight tube, smooth helically coiled tube and dimpled helically coiled tube are also discussed. The dimple helically coiled tube produces a higher heat transfer coefficient and frictional pressure drop compared to smooth helically coiled tube and smooth straight tube. The correlations have been proposed to predict the Nusselt number and frictional pressure drop multiplier during condensation of R-134a inside horizontal dimpled helically coil tube.

1. Introduction

The condenser is an essential part of any refrigeration and air conditioning unit which condenses a substance from its gaseous to liquid state by removing the latent heat. Nowadays, the effective design of the condenser is the important for the industries to obtain a maximum heat transfer with a smaller amount of pressure drop. As such as, helically coiled tube have been widely used to enhance the heat transfer by producing centrifugal effect on the flow inside the tube [1]. Nevertheless, A number of literature has been studied on two phase flow in smooth round tube [2]. Dobson and Chato [3] reported the experimental heat transfer coefficient data with refrigerants R22, R134a, R410A, R32/R125 (60/40% by mass) inside smooth round horizontal tubes with inner diameters ranging from 3.14 to 7.04 mm. They also proposed the correlation to predict the heat transfer coefficient for the stratified and annular flow pattern. Cavallini et al. [4] experimentally measured the heat transfer coefficient and pressure drop of pure HFC refrigerants (R134a, R125, R236ea, R32) and the nearly azeotropic HFC refrigerant blend R410A inside a smooth tube of diameter 8 mm at saturation temperature in the range between 30 °C and 50 °C with mass velocities varying from 100 to 750 kg m^{-2} s^{-1}. The results show that, during condensation of pure fluids and nearly azeotropic mixtures, in the annular flow regime, the heat transfer coefficient increases with rise of mass velocity and vapor quality. Jung et al. [5] carried out the experimental heat transfer coefficient data with refrigerants R12, R22, R32, R123, R125, R134a, and R142b in a horizontal plain copper tube of 9.52 mm outside diameter and 1 m length at a fixed refrigerant saturation temperature of 40 °C with mass fluxes of 100, 200, 300 kg m^{-2} s^{-1} and heat flux of

* Corresponding author.
E-mail address: iitranandsolanki@gmail.com (A.K. Solanki).

https://doi.org/10.1016/j.applthermaleng.2017.10.026
1359-4311/

Nomenclature

A	heat transfer area, m^2
D_e	Dean number
C_p	specific heat at constant pressure, J kg^{-1} K^{-1}
Re	Reynolds number
d	tube diameter, mm
EF	enhancement factor
D	coil mean diameter, mm
PF	penalty factor
g	gravity, 9.81 m^2 s^{-1}

Greek symbols

e	depth of dimple, mm
α	void fraction
o	diameter of dimple, mm
χ	Martinelli parameter
s	pitch of dimple, mm
θ	helix angle, °
p	helical pitch, mm
ρ	density, kg m^{-3}
G	mass velocity, kg m^{-2} s^{-1}
μ	dynamic viscosity, kg m^{-1} s^{-1}
h	heat transfer coefficient, W/m^2 K
ϕ	two-phase multiplier
h	enthalpy, J/kg
Δ	difference
l	length, m

Subscripts

Nu	Nusselt number
a	acceleration
K	thermal conductivity, W m^{-1} K^{-1}
G	gravitational
x	vapor quality
f	frictional
Q	heat transfer rate, W
l	liquid
T	temperature, °C
g	gas
ph	preheater
Eq	equivalent
P	pressure, kPa
exp	experimental
$\dot{m}$	mass flow rate, kg/s
fg	latent heat of vaporization
Fr_v	vapor Froud number
sat	saturation condition
R	refrigerant
i	inner
w	wall
o	outer
ts	test section
w	water
tt	turbulent–turbulent
out	outlet
W	water
in	inlet
Pr_l	Prandtl number
T	total

7.3–7.7 kW m^{-2}. They found that the heat transfer coefficient of refrigerant R142b and R32 were higher than those of R22 by 8–34% at the same mass flux while heat transfer coefficient of refrigerant of refrigerant R134a and R123 were similar to those of R22. Hossain et al. [6] conducted the experiments with refrigerants R1234ze(E), R32, R410A and a zeotropic mixture R1234ze(E)/R32 (55/45 mass%) inside a water heated double tube heat exchanger. They investigated that the experimental heat transfer coefficient of R1234ze (E) is lower than R1234ze (E)/R32 (55/45 mass %), R410A and R32 by 11%, 56% and 83%, respectively.

Moreover, a few paper are also reported on the two phase-flow of refrigerant inside the dimpled straight tube during condensation process. Aroonrat and Wongwise [7] examined the condensation heat transfer coefficient and frictional pressure drop of R-134a inside the smooth and spherical dimpled straight tube at saturation temperature of 40°, 45° and 50 °C with the mass flow rate of 300, 400 and 500 kg m^{-2} s^{-1}. They found that the heat transfer coefficient ratio for spherical dimpled straight tube varies from 1.27 to 1.37 at 300 kg m^{-2} s^{-1}, 1.28 to 1.36 at 400 kg m^{-2} s^{-1} and 1.26 to 1.41 at 500 kg m^{-2} s^{-1}, respectively, while, the two-phase friction factor ratio varies from 2.8 to 3.7 at 300 kg m^{-2} s^{-1}, 2.7 to 4.2 at 400 kg m^{-2} s^{-1} and 2.6 to 4.1 at 500 kg m^{-2} s^{-1}, respectively. Sarmadian et al. [8] investigated the convective condensation heat transfer and frictional pressure drops of R-600a inside a helically dimpled tube and a plain tube of internal diameter 8.3 mm at saturation temperature of 38 and 48 °C with mass flux varying from 114 to 368 kg m^{-2} s^{-1}. They noticed that the heat transfer coefficients of the dimpled tube were 1.2–2 times of those in smooth tube with a pressure drop penalty ranging between 58% and 195%.

Besides, a few research work have been performed on the heat transfer and pressure drop characteristics inside helical coiled tube. Kang [9] carried out the experimental study of heat transfers and pressure drops data of R-134a inside long helical coil tube. The inner diameter, outer diameter, coil diameter and number of turns of the tube were taken 12.7 mm, 21.2 mm, 177.8 mm, 34.8 mm and 10, respectively. The test runs were executed at different refrigerant mass flux varying from 100 to 400 kg m^{-2} s^{-1}, cooling water flow Reynolds number range of 1500–9000, cooling tube wall temperature at 12 °C and 22 °C and fixed saturation temperature of 33 °C. The results revealed that the overall heat transfer coefficient raised with increase of the water mass flux. The heat transfer and pressure drop decreased with increase of tube wall temperature from 12 °C and 22 °C. Yu et al. [10] conducted an experimental investigation of heat transfer of R-134a during condensation inside horizontal, inclined and vertical helical tube at refrigerant mass flux from 100 to 400 kg m^{-2} s^{-1}, cooling water Reynolds number between 1500 and 10000. They investigated that the helical tube orientation had significant influence on the overall heat transfer coefficients. The highest and lowest heat transfer coefficient was observed at inclined position and vertical position, respectively. Han et al. [11] reported the experimental results of condensation heat transfer and pressure drop of R-134a inside helical tube with mass flux vary from 100 to 420 kg m^{-2} s^{-1} at a different condensation saturation temperature 35, 40 and 46 °C. They observed that the refrigerant mass flux and the saturation temperature had a significant influence on the heat transfer coefficient. Wongwises and Polsongkram [12] presented experimental studies on two-phase flow condensation heat transfer and pressure drop of R-134a inside concentric helical coil tube in tube condenser. The experimental measurement were performed at different saturation temperature 40 and 50 °C with refrigerant mass flux between 400 and 800 kg m^{-2} s^{-1}. The results showed that the heat transfer coefficient of the helical coiled tube were about 33–53%