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Heat transfer characteristics of R410A-oil mixture flow boiling inside a 7 mm straight smooth tube

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Abstract

Two-phase flow patterns and heat transfer characteristics of R410A-oil mixture flow boiling inside a straight smooth tube with the outside diameter of 7.0 mm were investigated experimentally. The experimental conditions include the evaporation temperature of 5 °C, the mass flux from 200 to 400 kg m^{-2} s^{-1}, the heat flux from 7.56 to 15.12 kW m^{-2}, the inlet vapor quality from 0.2 to 0.7, nominal oil concentration from 0% to 5%. The test results show that the heat transfer coefficient of R410A-oil mixture increases with mass flux of refrigerant-oil mixture; the presence of oil enhances the heat transfer at the range of low and intermediate vapor qualities; there is a peak of local heat transfer coefficient at about 2–4% nominal oil concentration at higher vapor qualities, and the peak shifts to lower nominal oil concentration with the increasing of vapor qualities; higher nominal oil concentration gives more detrimental effect at high vapor qualities. The flow pattern map of R410A-oil mixture was developed based on refrigerant-oil mixture properties, and the observed flow patterns match well with the flow pattern map. New correlation to predict the local heat transfer of R410A-oil mixture flow boiling inside the straight smooth tube was developed based on flow patterns and local properties of refrigerant-oil mixture, and it agrees with 90% of the experiment data within the deviation of ±25%.

Keywords: Heat transfer; Correlation; R410A; Oil; Flow pattern

1. Introduction

Due to the phase-out of R22 early this century, searching for a replacement for R22 has been intensified in recent years. The near azeotropic refrigerant mixture of R410A, a mixture of 50 wt.% R32 and 50 wt.% R125, has been considered as one of the primary replacements for R22 in the air-conditioning system applications. Under real working conditions of a compression air-conditioning system, some amount of oil inevitably circulates with the refrigerant and has a significant impact on refrigerant evaporation heat transfer characteristics because oil changes the refrigerant thermal and transport properties, such as saturation temperature, density, viscosity, thermal conductivity, etc [1,2]. Consequently, heat transfer behaviors of R410A-oil mixture flow boiling inside tubes must be known in order to investigate the overall performance of the heat exchangers of R410A air-conditioning systems.

Two-phase heat transfer performance of oil-free R410A flow boiling inside tubes have been reported by Park and Hrnjak [3], Pamitran et al. [4], Yun et al. [5], Kim and Shin [6], Wellsandt and Vamling [7], Greco and Vanoli [8–10], Kim et al. [11], Goto et al. [12], Wang et al. [13], Ebisu and Torikoshi [14] and others. Although there are many researches on evaporation heat transfer characteristics of refrigerant-oil mixtures, few papers report that of R410A-oil mixture. The researched refrigerant-oil mixtures include R12-oil mixture [15–18], R22-oil mixture [15,19–24],

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Nomenclature

A	effective heating surface area, m^2
C	coefficient in Eq. (16)
d	inside diameter, m
E	two-phase heat transfer multiplier, dimensionless
EF	enhanced factor for heat transfer, dimensionless
G	mass flux, $kg\ m^{-2}\ s^{-1}$
h	specific enthalpy, $kJ\ kg^{-1}$
Ja	$\Delta T/(G\,r)$, dimensionless
K	constant in Tichy correlation
m	mass flow rate, $kg\ s^{-1}$
n	coefficient in Eq. (16)
Q	heat addition, kW
q	heat flux, $kW\ m^{-2}$
p_r	reduced pressure, dimensionless
Pr	Prantle number, dimensionless
P	pressure, Pa
Re	Reynolds number, dimensionless
T	temperature, °C
x	vapor quality, $kg\ kg^{-1}$
X_{tt}	Martinelli parameter
α	heat transfer coefficient, $W\ m^{-2}\ K^{-1}$
ε	void fraction, dimensionless
ω	oil mass fraction, $kg\ kg^{-1}$
ρ	density, $kg\ m^{-3}$
δ	thickness of liquid film, m
θ	dry angle, radian
μ	dynamic viscosity, Pa s
σ	surface tension, $N\ m^{-1}$
λ	heat conductivity, $W\ m^{-2}\ K^{-1}$
ψ	mole fraction, dimensionless

Subscripts

bub	bubble
cb	convective boiling
dry	dry tube surface
in	inlet
local	local
L	liquid
nb	nuclear boiling
no	nominal
o	oil
out	outlet
pre	pre-heater
r	refrigerant
sat	saturated
test	test section
tp	two-phase
V	vapor
wet	wet tube surface
W	wall

R134a-oil mixture [25–31], R407C-oil mixture [32,33], etc. Available experimental data of refrigerant-oil mixtures flow boiling inside tubes show that the presence of small amount oil may cause an enhancement of heat transfer coefficient at the range of low and intermediate vapor qualities, while significant deterioration in boiling performance occurs at high vapor qualities for the higher oil concentrations [16–20,29–33]; the oil with higher viscosity gives more deterioration to the heat transfer than the oil with lower viscosity [22,26]. It can be deduced from previous studies of refrigerant-oil mixture that different refrigerant-oil mixtures may have different evaporation heat transfer characteristics, and there may be large deviation by using the heat transfer coefficient correlation of one refrigerant-oil mixture to predict that of the other refrigerant-oil mixtures. So the tests of flow boiling heat transfer characteristics using R410A-oil mixture as the working fluid are necessary.

The purpose of this study is to obtain experimental data of the local evaporation heat transfer characteristics of R410A-oil mixture flow boiling inside the straight smooth tube, to verify the state-of-the-art heat transfer coefficient correlations of refrigerant-oil with the experimental data, and finally to present a better correlation for predictions of local flow boiling coefficient of R410A-oil mixture in smooth tubes.

2. Experiment apparatus

2.1. Circuits layout of refrigerant and oil

The experiment rig used for R410A-oil mixture, schematically shown in Fig. 1, consists of three loops: a refrigerant main loop, a refrigerant by-path loop and a lubricant oil loop. The test section is insulated with glass wool and double layers of rubber foam to reduce heat loss to the surroundings. Heat losses from the pre-heater and the test section are estimated less than 3.3%. Wei et al. [20] made a detailed introduction to the experimental rig when he used it for the tests of R22 and R22-oil mixture.

In order to investigate the evaporation heat transfer performance of oil-free refrigerant, three high-efficient oil separators were installed in series at the compressor exit to remove the oil carry-over in the discharged vapor from the compressor. The effectiveness of the oil separators is determined by a boiling-off-and-weight method based on ASHARE standard 41.1 [34]. Three samples of the refrigerant-oil mixture at the condenser outlet are taken for maximum oil discharge from the compressor at the frequency (50 Hz). The average sampled oil concentration of only 0.02% shows that the three oil separators work well.