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An experimental investigation and modelling of flow boiling heat transfer of isobutane-compressor oil solution in a horizontal smooth tube

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ABSTRACT

Experimental results of local heat transfer coefficients for the boiling of working fluids (solutions of R600a with mineral naphthenic oil ISO VG 15) in a smooth tube with a small diameter (5.4 mm) are presented. The experiments have been performed in the following ranges: for the inlet pressure from 65.7 kPa to 82.2 kPa, for the heat flux from 2500 to 3300 W m^{-2}, and for the mass velocity of the working fluid from 11.90 to 15.99 kg m^{-2} s^{-1}). The quantitative estimation in reduction of the heat transfer coefficient of the wetted surface in the evaporator at a high oil concentration in the mixture is examined. The influence of heat flux and mass velocities on the values of the local heat transfer coefficients is analyzed. The equation for the modelling of the local heat transfer coefficient for boiling of an isobutane/compressor oil solution flow in the tube is suggested.

Etude expérimentale et modélisation du transfert de chaleur d'écoulement en ébullition d'isobutane-solution d'huile de compresseur dans un tube lisse horizontal

Mots clés : Coefficient de transfert de chaleur ; Fluide actif ; Ebullition ; Isobutane ; Huile ; Concentration ; Corrélation

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Nomenclature

A, n	empirical constants in Equation (11)
B, f	empirical constants in Equation (13)
c_p	constant pressure specific heat, kJ kg^{-1} K^{-1}
d	diameter, mm
h	enthalpy, kJ kg^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
L	length, mm
$\dot{M}$	mass flow rate, kg s^{-1}
$\dot{m}$	mass velocity, kg m^{-2} s^{-1}
p	pressure, bar
$\dot{Q}$	heat load, W
$\dot{q}$	specific heat flux, W m^{-2}
WF	working fluid
ROS	refrigerant oil solution
T	temperature, K
w	mass concentration, %
x	vapor quality, kg kg^{-1}

Greek letters

α	heat transfer coefficient, W m^{-2} K^{-1}
δ	thickness, mm
ε	void fraction
θ	angle, rad
μ	dynamic viscosity, N s m^{-2}
ρ	density, kg m^{-3}
σ	surface tension, N m^{-1}

Subscripts

aver	average
cb	convective boiling
dis	discharge
dry	dry
inner	inner
inlet	inlet
l	liquid
local	local
nb	nucleate boiling
O	pure oil
R	pure refrigerant
ROS	refrigerant/oil solution
suc	suction
v	vapor
w	water
wet	wetted
WF	working fluid

1. Introduction

Lack of oil separators in a small refrigeration system leads to unavoidable circulation of small amounts of compressor oil through the system that, together with refrigerant, forms working fluid (WF). The concentration of compressor oil in the refrigerant can vary from 0.5 to 5% by weight, depending on the type of compressor (Thome, 2004; ASHRAE, 2005). Mutual solubility of the compressor oil with the refrigerant has a significant impact both on heat transfer in the apparatus and the refrigeration machine operation in general.

Recently, considerable attention has been paid to studying the heat transfer coefficient of refrigerant/oil solutions (ROS). Several investigations have been carried out to study the process of boiling of ROS, such as: R12/oil (Cawte et al., 1996; Poiate and Gasch, 2006), R22/oil (Wojtan et al., 2005; Wei et al., 2007a, 2007b), R134a/oil (Zurcher et al., 1997; Castro and Gasche, 2006; Dawidowicz and Cieśliński, 2012), R410A/oil (Hu et al., 2010, 2014), CO_2/oil (Gao et al., 2007), and others. In reviews of Shen and Groll (2005) and Filho et al. (2009) the authors analyze the effect of compressor oil admixtures on the heat transfer of refrigerant during the boiling process. Still the problem of the influence of oil admixtures in the refrigerant on the heat transfer process at various parameters of the working fluid requires further investigation.

Thome et al. (2008) presented a comprehensive review of the flow boiling heat transfer, pressure drop, and flow patterns of ammonia and hydrocarbons applied in refrigeration systems. The authors noted that there is apparently no study related to the effect of compressor oil admixtures on the flow boiling of hydrocarbons under domestic refrigerator operating conditions (low mass velocities and heat flux, stratified or wavy stratified flow patterns).

Thus, Wen et al. (2007) experimentally investigated a flow boiling of refrigerant R600a and R290 mixed with the lubricating oil (EMKARATE) in serpentine, small-diameter (2.46 mm) U-tubes. The experiments were conducted at the nominal inlet pressure of 186.2 kPa with vapor qualities (0–0.76), mass flux of 100–320 kg m^{-2} s^{-1}, and inlet oil concentrations of 0–5% oil. The authors noted that at low vapor quality ($x < 0.4$), the presence of compressor oil had no significant effect on the heat transfer coefficient. In addition, in the high vapor quality region ($x > 0.4$), the heat transfer coefficient of R600a and R290 with oil decreased significantly. This can be explained by the fact that the effects of an oil-rich liquid layer dominate the foaming enhancement effect and lower the heat transfer coefficient. The authors also pointed out that larger compressor oil concentrations degraded the heat transfer coefficient. Moreover, the paper showed the heat transfer coefficient increase with increasing the refrigerant/oil solution mass velocities.

Bjork and Palm (2008) reported on the experimental investigation of the flow boiling heat transfer in a typical domestic refrigerator evaporator at low mass velocities and heat flux. The object of the investigation was an isobutane/mineral oil solution. The oil concentration at the inlet of the evaporator was 0.2% by mass and was not considered. The obtained data showed that the heat transfer coefficient decreases with increasing quality and heat flux at the lowest mass flux tested (as low as 21 kg m^{-2} s^{-1}). This was explained by partial perimeter dry out. Moreover, the heat transfer coefficient increases with increased quality of higher mass fluxes (33 and