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Experimental study on saturated flow boiling heat transfer of R170/R290 mixtures in a horizontal tube

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ABSTRACT

Saturated flow boiling heat transfer coefficients in a horizontal tube of the binary mixtures of R170/R290 were measured. The experiments were performed at three different mixture compositions and various saturation pressures from 0.35 to 0.57 MPa. The results were obtained over the mass fluxes ranging from 63.6 to 102.5 kg m^{-2} s^{-1} and heat fluxes ranging from 13.1 to 65.5 kW m^{-2}. The influences of quality, saturation pressure, heat flux and mass flux on the heat transfer characteristic were examined and discussed. The flow pattern of mixture was shown and the transitions of flow pattern occur at higher mass flux and quality for mixtures than for pure substance. A modified correlation was developed based on the previous research of our group on the pool boiling heat transfer and the database obtained from this study. The comparison of the experimental heat transfer coefficient with the predicted value using the present correlation shows that the total mean deviation is 15.97% for R170/R290 mixtures.

Etude expérimentale sur le transfert de chaleur lors de l'ébullition en écoulement saturé des mélanges de R170 et de R290 à l'intérieur d'un tube horizontal

Mots clés : Échangeur de chaleur ; Évaporateur ; Tube horizontal ; Expérimentation ; Transfert de chaleur ; Mélange ; Éthane ; Propane

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Nomenclature

C_p	specific heat ($J\,kg^{-1}\,K^{-1}$)
d_h	hydraulic diameter (m)
E	enhancement factor
G	mass flux ($kg\,m^{-2}\,s^{-1}$)
h	heat transfer coefficient ($kW\,m^{-2}\,K^{-1}$)
H_{lv}	latent heat ($J\,kg^{-1}$)
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
L	length of channel (m)
M	molecular weight ($g\,mol^{-1}$)
m	mass flow rate ($kg\,s^{-1}$)
P	pressure (Pa)
P_r	reduced pressure
$Pr = \mu C_p/k$	Prandtl number
q	heat flux ($kW\,m^{-2}$)
Q	heat input (W)
$Re = G d_h/\mu_l$	Reynolds number
S	suppression factor
T	temperature (K)
T_b	bubble point temperature (K)
T_d	dew point temperature (K)
ΔT_{id}	ideal temperature difference (K)
ΔT_{db}	temperature difference between dew point and bubble point (K)
X	vapor quality
x	liquid mole fraction of more volatile component
x_M	liquid composition based on mass of more volatile component
y	vapor mole fraction of more volatile component

Greek symbols

μ	viscosity (Pa s)
ρ	density ($kg\,m^{-3}$)
σ	surface tension ($N\,m^{-1}$)

Subscripts

1	pertains to the more volatile component
2	pertains to the less volatile component
ave	average
exp	experiment
i	ideal
in	inlet
l	liquid
m	mixture
nb	nucleate boiling
pre	predict
preh	preheater
sat	saturation
sp	single-phase
tp	two-phase
v	vapor
w	wall

1. Introduction

In recent decades, great efforts have been made to search for more efficient and environment-friendly refrigerant alternatives from the environment protection point of view. The natural refrigerants are suitable selections because they have good environmental criteria, and for some of them, high thermodynamic performances. Hydrocarbons belong to the group of natural refrigerants. There is gradually an increasing acceptance of using hydrocarbon refrigerants even if they are flammable. It has been known that non-azeotropic refrigerant mixtures can increase the energy efficiency of certain refrigeration equipment under optimized conditions. Chang et al. (2000) presented a survey of performance and heat transfer characteristics of hydrocarbon refrigerants (R290, R600, R600a, R290/R600a and R290/R600) in a heat pump system. As one kind of natural refrigerant, R170/R290 mixture can be used as a potential substitute to either R22 or R13 at different concentration. One potential use of R170/R290 mixture at the case of R290 concentration dominating the mixture is substitute to R22. In reference Park and Jung (2009), thermodynamic performance of R170/R290 mixture was measured on a heat pump bench tester in an attempt to substitute R22. Moreover, it is reported that the R170/R290 mixtures have been used to substitute R22 in milk silo refrigeration systems in reference Cleland et al. (2009). When the concentration of R170 dominating the mixture, this mixture of R170/R290 can be used to substitute to R13 or R503, which is traditional used in the two-stage cascade refrigeration system for −80 °C temperature range application. For this case, R290 in the mixture is used to solve the oil circulating problem in the refrigeration system.

There are a considerable number of experimental studies and empirical correlations that can be employed in calculation of the heat transfer coefficient of refrigerant mixtures for flow boiling in a horizontal tube. Thome (1996) presented an excellent review on this topic. The mixture effect on the heat transfer coefficient was taken into account by Palen and Small (1964) as a function of the boiling range firstly, which is defined as the temperature difference between the dew and bubble points. Jain and Dhar (1983) presented experimental data of flow boiling of R12/R13 mixtures in a horizontal tube. They believed that the heat transfer coefficient degradation caused by the mixture effect in the dominant convective evaporation region is rather small, while in the nucleate flow boiling region the reduction is quite significant. The analysis of the experimental data of R12/R114 binary mixtures in upflow forced convective boiling obtained by Celata et al. (1993) shows that the degradation of the binary mixtures boiling heat transfer appears to be dependent on the saturation pressure (increasing as the pressure increases), mass flux (decreasing as mass flux increases) and quality (decreasing as quality increases). Recently, Chiou et al. (2009) conducted an experimental study of the evaporation heat transfer characteristics for a non-azeotropic refrigerant mixture of R22/R124 in a horizontal smooth tube, in which the reduction of mixture heat transfer coefficients depends on the composition and decreases with the mass flux. Neeraas and Fredheim (2004) measured the two-phase shear flow heat transfer