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A numerical investigation of flow boiling of non-azeotropic and near-azeotropic binary mixtures

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ABSTRACT

The flow and heat transfer characteristics of binary refrigerant mixtures in a heated horizontal tube were investigated numerically. The pressure drop, temperature profile, and heat transfer coefficient for non-azeotropic and near-azeotropic mixtures of different bulk compositions were obtained. It is found that the non-linear physical properties of the mixtures strongly affect the pressure drop characteristics. Both the fluid properties and mass transfer resistance are responsible for the heat transfer characteristics. The mass transfer resistance has a more significant influence on the nucleate boiling than the convective evaporation for non-azeotropic mixtures, while the resistance can be neglected for near-azeotropic mixtures.

Une étude numérique de l'ébullition en écoulement de mélanges binaires non azéotropiques et quasi-azéotropiques

Mots clés : Modèle numérique ; Frigorigènes non azéotropiques ; Frigorigènes quasi-azéotropiques ; Chute de pression ; Transfert de chaleur

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Nomenclature

C_0	Initial bulk composition
D_i	inner diameter [m]
e	specific energy [J kg^{-1}]
f	friction factor
G	mass flux [kg/m^{2}s]
h	heat transfer coefficient [W/m^{2}K]
H_{lv}	latent heat of vaporization [J kg^{-1}]
k	mass transfer coefficient [kg/m^{2}s]
$\mathcal{D}_m$	mass diffusivity [m^2/s]
$\mathcal{D}_t$	thermal diffusivity [m^2/s]
P	pressure [Pa]
P_r	reduced pressure, $P/P_{critical}$
Pr	Prandtl number
Q	heat flux [W/m^2]
Re	Reynolds number
T	temperature [K]
V	velocity [m s^{-1}]
X	liquid mole fraction of volatile component
x	vapor quality
X_m	liquid mass fraction of volatile component
Y	vapor mole fraction of volatile component
Y_m	vapor mass fraction of volatile component
z	axial coordinate along the pipe [m]

Greek symbols

α	void fraction
Γ	evaporation rate [kg/m^{3}s]
λ	thermal conductivity [W m^{-1} K^{-1}]
μ	viscosity [Pa s]
Φ	two-phase multiplier
ρ	density [kg/m^3]
σ	surface tension [N m^{-1}]
τ_w	shear stress [N/m^2]
ε	tube roughness [m]

Subscripts

0	inlet condition
l/lo	liquid/liquid only
tp	two phase
v/vo	vapor/vapor only
w	pipe wall

1. Introduction

During the past decades, Chlorofluorocarbon (CFC) and hydroChlorofluorocarbon (HCFC) have been widely used in many refrigerant systems, such as heat pumps and air-conditioners. However, they are being gradually phased out due to their impact on ozone depletion and global warming and consequently some refrigerant mixtures are becoming attractive as good substitutes of the phased-out pure refrigerants. There is an increasing effort on research and development of refrigerant mixtures in order to achieve similar thermophysical properties as for existing refrigerants and to meet the requirements of industrial systems. However, mixture refrigerants do not show the same thermohydraulic behavior as single-component refrigerants. For instance, flow patterns and therefore pressure drop are not the same during mixtures condensation (Kattan et al., 1995) and a delay in dry-out occurrence and heat transfer coefficient degradation has been observed during evaporation of mixture refrigerants (Kattan et al., 1998; X. Boissieux et al., 2000).

A lot of experimental work has been done to study the fundamental aspects of two-phase flow of refrigerant mixtures, with main focus on the development of pressure drop and heat transfer coefficient correlations, which are summarized in the review papers by Thome (1996), Cheng and Mewes (2006), etc. However, the numerical simulation of the phenomenon has received less attention. Shock (1976) solved the heat and mass balance equations in upward annular flow, and also examined the effects of mass transfer resistances in the vapor and liquid phases. Among his studied cases significant differences from the equilibrium case were observed, caused by the mass transfer resistance in the vapor. Zhang et al. (1997) studied the boiling heat transfer of a ternary refrigerant mixture inside a horizontal smooth tube by a theoretical model considering the effect of mass diffusion near the gas–liquid interface. They also obtained the similar conclusion with Shock's analysis that the mass transfer resistance in the vapor phase is dominant while the mass transfer resistance in the liquid phase is negligible. Chiou et al. (1996) used a two-phase separated model to simulate the evaporation process of non-azeotropic refrigerants in horizontal tubes. The model assumed annular flow regime and was used to compare the behavior of different non-azeotropic mixtures during boiling, showing the concentration evolution in the liquid and vapor phases along the tube. Sami and Tribes (1998) proposed a homogeneous model to compute the pressure drop of binary mixtures in a capillary tube. Raja et al. (2009) made a numerical study on flow boiling of a ternary mixture under a varied

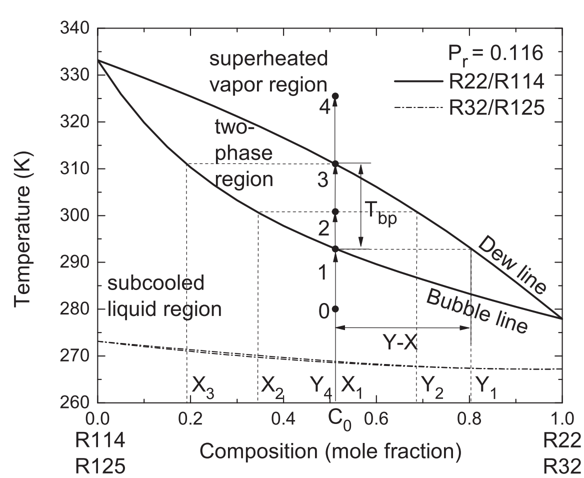

Fig. 1 – Temperature-composition diagram for mixtures R22/R114 and R32/R125 atPr = 0.116.