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# Comparative experimental study on flow boiling heat transfer characteristics of pure and mixed refrigerants

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ABSTRACT

An experimental study is carried out to investigate the characteristics of the flow boiling heat transfer for different fluid, namely, pure refrigerant (R134a), quasi-azeotropic mixture (R410A) and zeotropic mixture (R407C). The test section is a smooth horizontal tube (7.0 mm ID) uniformly heated by the resistance heating effect. The flow boiling characteristics of the refrigerants are evaluated varying: (i) the refrigerant mass velocities within the range 100–400 $kgm^{-2}s^{-1}$; (ii) the heat fluxes within 3.0–10.0 $kWm^{-2}$; (iii) the inlet temperatures to the evaporator within 5°C-9°C. In this study, the effect on the heat transfer coefficient and two-phase pressure drop of vapor quality, mass velocity, imposed heat flux and fluid thermophysical properties are examined in detail. Moreover, an assessment of predictive methods is provided for local heat transfer coefficients; also a direct comparison of flow regimes visualizations for refrigerants with a flow pattern map available in the literature is presented.
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# Etude comparative expérimentale sur les caractéristiques de transfert de chaleur d'écoulement en ébullition de frigorigènes purs ou mélangés

*Mots clés* : Ecoulement en ébullition ; Coefficient de transfert de chaleur ; Chute de pression ; R134a ; R410A ; R407C

## 1. Introduction

The detailed understanding of the two-phase heat transfer and pressure drop and associated bubble characteristics is essential in order to properly design an air conditioning and refrigeration heat exchanger system. The advantages of the small channel used in heat exchangers are its high heat transfer coefficient, significantly lessening the size of the heat exchangers, and lower required fluid volume. The decreasing size also permits heat exchangers to achieve a significant weight reduction, a lower inventory, a low installation cost,

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**Nomenclature**

| | |
|---|---|
| $C_P$ | specific heat at constant pressure ($Jkg^{-1}K^{-1}$) |
| $D$ | diameter (m) |
| $G$ | mass velocity ($kgm^{-2}s^{-1}$) |
| $g$ | gravitational acceleration ($ms^{-2}$) |
| $h_{ev}$ | local heat transfer coefficient ($Wm^{-2}K^{-1}$) |
| $h_{ev_{avg}}$ | average heat transfer coefficient ($Wm^{-2}K^{-1}$) |
| $E$ | specific enthalpy ($Jkg^{-1}$) |
| $I$ | electric current (A) |
| $k$ | thermal conductivity ($Wm^{-1}K^{-1}$) |
| $L$ | length of tube in flow direction (m) |
| $\dot{m}$ | total mass flow rate ($kgs^{-1}$) |
| $M$ | molecular weight (dimensionless) |
| $P$ | pressure (Pa) |
| $q$ | heat flux ($Wm^{-2}$) |
| $Q$ | heat transfer rate (W) |
| $T$ | temperature (°C) |
| $t$ | time (s) |
| $V$ | electric potential (V) |
| $x$ | vapor quality (dimensionless) |
| $z$ | length, position (m) |

*Greek letters*

| | |
|---|---|
| $\mu$ | dynamic viscosity (Pa-s) |
| $\rho$ | density ($kgm^{-3}$) |
| $\sigma$ | surface tension ($Nm^{-1}$) |
| $\Delta$ | differential |

*Subscripts*

| | |
|---|---|
| avg | average |
| $b$ | bottom side |
| C | critical |
| $f$ | saturated liquid |
| $fg$ | latent quantity |
| G | gravitational |
| $g$ | saturated gas |
| $i$ | inside |
| IA | intermittent to annular flow transition in inlet |
| $o$ | outside |
| out | outlet |
| PH | pre-heater |
| Sat | saturation |
| TS | test section |
| $t$ | top side |
| $sl$ | left side |
| $sr$ | right side |

and furthermore an energy saving. Despite of those advantages, higher pressure loss with lowering the channel size because of the increase of wall friction always is being a doubt for industry to prefer a suitable tube diameter. The choice of a suitable refrigerant plays also an important role in the air conditioning and refrigeration systems design. An additional factor is that, the chlorofluorocarbon refrigerants (CFCs) have been proscribed in produced by the international protocols since 1996 and the hydrochlorofluorocarbons (HCFCs) will be phased out by 2020, due to the presence of chlorine elements in these refrigerants which are depleting the stratospheric ozone layer and raising the Total Equivalent Warming Impact (TEWI). Atmospheric Research and Environment Program (AREP) initiate to recognize the substitution of CFCs and HCFCs by some hydrofluorocarbons refrigerants (HFCs); among them pure fluid R134a, zeotropic blend R407C and quasi-azeotropic mixture R410A are considered to be the eligible alternatives and some are currently in use.

The literature relevant to the present study is reviewed in the following. The boiling heat transfer and flow characteristics in the small channels are important to design a compact heat exchanger. The channel size in a compact heat exchanger extensively affects its performance (Ghiaasiaan, 2008). The significance of the flow restriction by the small size channel was described by Kew and Cornwell (1997). They showed that the effects of the channel size became particularly significant when the Confinement number, $Co = (\{\sigma/[g(\rho_f - \rho_g)]\}^{0.5}/[D_o - D_i]) > 0.5$. Cheng and Mewes (2006) have presented a review with a detailed description of the physical effect of different channel diameter on flow boiling of several refrigerants mixtures in mini and small diameter tubes. Infact, any universal agreement is not clearly accredited in the present literature so far. Rather, several parameters and correlations have been presented by various researchers by the time being. Mehendale et al. (2000) have defined various small and mini heat exchangers in terms of hydraulic diameter, and according to his definition, the distinction between small diameter channels and normal size channels is 6 mm. Kandlikar (2002) distinguished the small diameter and normal size channels by 3 mm. Wolk et al. (2000) considered a hydraulic diameter of 6 mm as the criterion of small diameter in their study. Wongwises et al. (2000) took a hydraulic diameter of 7.5 mm as the standard of small diameter channels. Triplett et al. (1999) defined a dimensionless parameter to differentiate the flow channels with hydraulic diameters $D_h$ of the order, or smaller than, Laplace constant, $L = [\sigma/g(\rho_f - \rho_g)]^{0.5}$ as small diameter channels which are extensively applied in compact heat exchangers and small-sized refrigeration systems.

A review (Thome, 1996) of the recent literature on flow boiling of new refrigerants shows the strength and weakness in the existing boiling correlations. Recently, experiments on the horizontal flow boiling of refrigerant mixtures have been accomplished, and reported data indicate that the heat transfer coefficients for zeotropic mixtures are considerably lower than those for pure refrigerant. Several possible reasons for heat transfer degradation of refrigerant mixtures were identified by Kedzierski et al. (1992) such as a nonlinear variation of physical properties and circumferential and radial non-uniformity of concentration profiles. Wang et al. (1996) also accounted a considerable decrease of heat transfer coefficients for R407C than that a pure fluid. Greco and Vanoli (2005) have shown experimentally that the boiling heat transfer coefficients of R134a are higher than that of R410A and the difference increases with increasing the evaporating pressure. Greco (2008) has compared the flow

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