Peculiarities of determination of the heat transfer coefficient at boiling of non-azeotropic mixtures in tubes

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Abstract. In this work, the calculation techniques for determining the heat transfer coefficient for boiling non-azeotropic mixtures in tubes are described. In particular, the dependencies proposed by the authors of Shin et al. (1997) and Mezentseva et al. (2014). These dependencies were used to calculate and compare the experimental data on the heat transfer coefficients for the boiling of a non-azeotropic mixture R32 / R134a (30/70%) in copper smooth tube with a diameter of 6.34 mm. The results showed that the dependence of Mezentseva et al. (2014) is in good agreement with the experimental data with an accuracy of ± 15%. In addition, this dependence considers the corresponding heat exchange regime and requires less thermodynamic properties of the mixture in calculations.

1. Introduction
The design and modeling of heat exchangers require the equations to calculate the heat transfer coefficient at boiling of non-azeotropic mixtures, which take into account peculiarities of the process. It is believed that during binary mixtures boiling, a low-boiling component is intensively released, and accordingly, the solution concentration changes, and this leads to a change in the wall-liquid temperature difference. In addition, the heat transfer coefficient depends on the flow regime, mass flow rate \( x \), mass flowrate, pressure, heat flux, thermodynamic properties of refrigerant, etc. (figure 1).

![Figure 1. Flow boiling in a circular tube.](image-url)
The dependences presented in literature for calculation of heat transfer coefficients can be divided into two categories. The models of Liu and Winterton [1], Wattelet et al. [2], Bivens and Yokozeki [3], Shurshev [4], Danilova [5], etc. relate to the first category. In these studies, the calculation of heat transfer at liquid boiling in the horizontal tubes considers two components: heat transfer at the forced flow of pure liquid and heat transfer at nucleate boiling. In some works, it is proposed to summarize the contributions of evaporation and convection in the whole range of parameters, and other studies suggest using the asymptotic approach of Kutateladze [6]. The second category engages investigations of Mishra et al. [7], Bennett-Chen [8], Mezentseva et al. [9], etc. These works, like the studies of the first category, calculate two heat transfer components, but the effect of boiling is considered by means of the Lockhart-Martinelli (1949) parameter. The studies of Sami et al. [10-12], Shin et al. [13] take into account the difference of component concentrations in the liquid and vapor phases.

The present paper compares the experimental data of the heat transfer coefficient of a non-azeotropic mixture R32/R134a corresponding to evaporation in forced convection [14] with calculated dependences proposed by the authors Mezentseva et al. [9] and Shin et al. [13].

2. Results and discussion

2.1. Shin Correlation
Shin et al. [13] developed the following correlation equation 1 based on a fit to R32/R134a and R290/R600a data of three compositions (75/25, 50/50, 25/75 wt.%). This correlation is an enhancement model like Shah's (1976) and used a correction factor to account for the mass transfer effect due to the composition difference between liquid and vapor phases, considered a driving force for mass transfer at the interface:

\[ \frac{\alpha}{\alpha_{CON}} = (1 - C_f) \cdot F \] (1)

where
\[ \alpha_{CON} \] – a bulk convective contribution based on Dittus and Boelter's (1930)

\[ \alpha_{CON} = 0.023 \cdot \left( \frac{\lambda_{liq}}{d} \right) \cdot Re_{liq}^{0.8} \cdot Pr_{liq}^{0.4} \] (2)

\[ Re_{liq} \] – two-phase Reynolds number

\[ Re_{liq} = \left( \frac{G \cdot (1-x) \cdot d}{\mu_{liq}} \right) \] (3)

where
\[ F \] – Chen's (1996) two-phase correction factor
\[ F(X_n) = 1.0 \text{ for } X_n \geq 10 \]
\[ F(X_n) = 2.35 \cdot (0.213 + X_n^{-1})^{0.736} \text{ for } X_n < 10 \]

\[ X_n \] – Martinelli's (1949) parameter

\[ \frac{1}{X_n} = \left( \frac{x}{1-x} \right)^{0.9} \cdot \left( \frac{\rho_{liq}}{\rho_{vap}} \right)^{0.5} \cdot \left( \frac{\mu_{vap}}{\mu_{liq}} \right)^{0.1} \] (4)

where
\[ C_F = A \cdot \left| Y - X \right|^n \] (5)

\[ A \] – curved fitted coefficients (0.569 for R32/R134a)
\[ n \] – curved fitted coefficients (0.860 for R32/R134a)
\[ X \] – liquid phase composition (figure 2)
\[ Y \] – vapor phase composition (figure 2)
Figure 2. Determination of the constituents of the vapor and liquid phases experimental data of Yoshida taken from a database REFPROP Version 8.0.

2.2. Mezentseva Correlation
In the study of heat transfer in the rising stream of a steam-water mixture the authors Dengler, Addom's [15] proposed a dependence of the form:
\[
\alpha / \alpha_{CON} = A \times \left(1 / X_n \right)^n
\]

where
\[A, n\] – fitted coefficients \((A = 3.50; n = 0.50)\)

Using this dependence, other authors proposed using different \(A\) and \(n\) coefficients. For example:
\[A = 2.50; n = 0.75\] data of the author Schroock and Grossman (1959)
\[A = 2.72; n = 0.58\] data of the author Wright (1961)
\[A = 2.17; n = 0.70\] data of the author Collier and Pulling (1962)

Dependence of the Mezentseva et al. [9] equation 7 was obtained by processing the experimental data of various authors on boiling in non-azeotropic mixtures R22/R114, R22/R142b and R32/R134a: Shin (1997), Kim (1999), Hihara, Zhang (1997), Ding Chang (1986), Shurshev (1997). These experiments had been carried out in horizontal stainless smooth tubes and in copper smooth tubes, mass flowrate was within 50 - 583 kg/m²·s, specific heat flux was within 1 - 45 kW/m².

\[
\alpha / \alpha_{CON} = 2.33 \times \left(1 / X_n \right)^{0.78}
\]

2.3. Experimental data Yoshida
Yoshida (1999) in the work [14] presented results the boiling of a non-azeotropic mixture of R32 / R134a (30/70 wt. %) in copper smooth tube with a diameter of 6.34 mm (heat flux was 20,30 kW/m², mass flowrate was 300, 500 kg/m²·s).

The results of calculations for the equalities (1) - (7) are shown in figure 3 and figure 4. At processing experimental data, the properties of non-azeotropic mixture are taken from the REFPROP Version 8.0 [16] database.
Figure 3. A comparison of the experimental data of Yoshida for a non-azeotropic mixture of R32/R134a (30/70%) at a mass flowrate 300 kg/m²·s with the dependence by equation 5.

Figure 4. A comparison of the experimental data of Yoshida for a non-azeotropic mixture of R32/R134a (30/70%) at a mass flowrate 300 kg/m²·s with the dependence by equation 7.
3. Conclusions
The presented dependences for calculating the boiling of non-azeotropic mixtures in the tubes are in good agreement with the experimental data with an accuracy of ±15%.

Dependence of Shin et al. to determine the heat transfer coefficient requires not only a greater number of thermodynamic properties, but it is also necessary to take into account the temperature difference in the liquid and vapor phases of the refrigerant mixture, which is difficult to do without having a database REFPROP. In addition, the first experimental points have a greater percentage of deviation, because this dependence does not describe the initial heat exchange process.

Dependence of Mezentseva et al. is in good agreement with the experimental data. This dependence requires less thermodynamic properties and takes into account the heat exchange regime.

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