Heat transfer correlations for flow boiling of hydrocarbon mixtures inside horizontal tubes

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Background

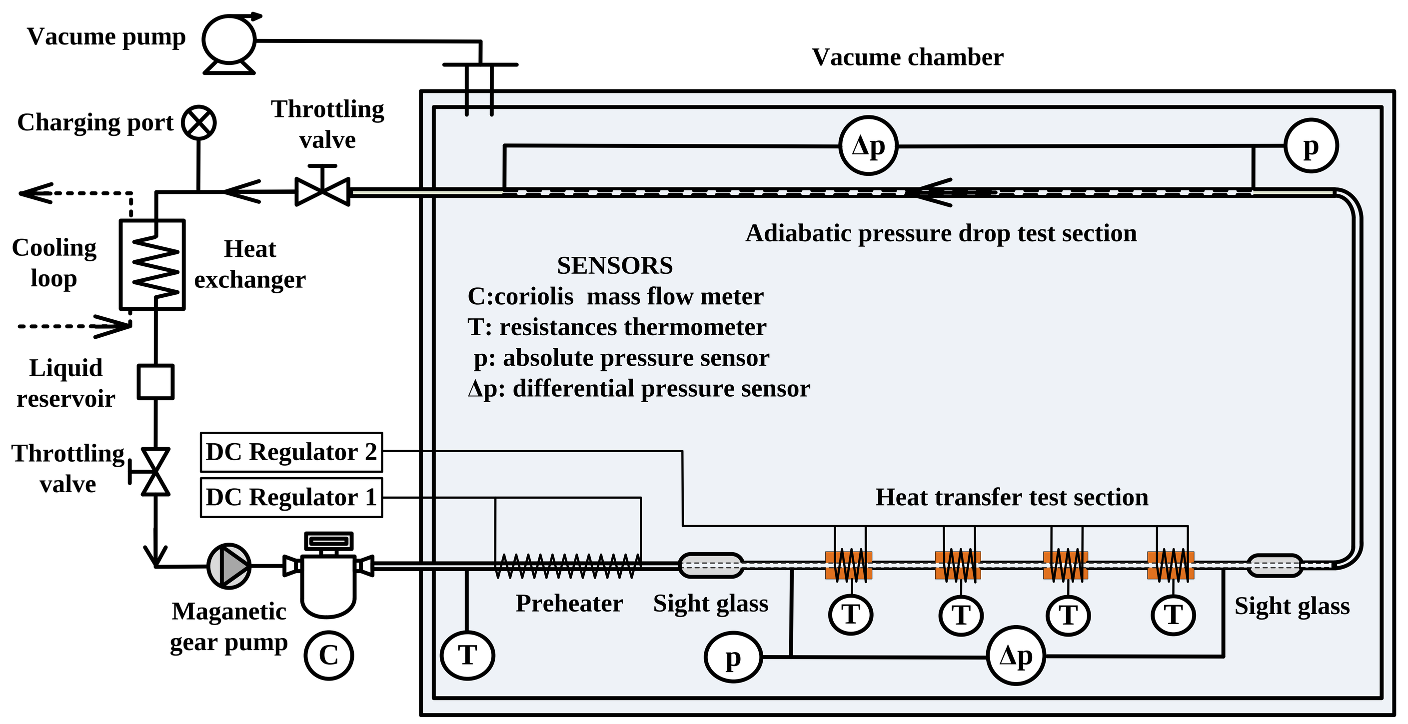
The hydrocarbons and its mixtures are suitable for environment-friendly refrigerant alternatives because of their good environmental criteria and high thermodynamic performances. Additionally, methane (R50), ethane (R170) and propane (R290) are not only the main components of the natural gas but also the natural refrigerants which are used in mixture Joule-Thomson cryogenic refrigerators and Liquefied Natural Gas refrigerant cycles. Therefore, the flow boiling heat transfer prediction of hydrocarbon mixtures is extremely important in many industrial fields.

Objectives

- ❖ Extending the proposed correlation to predict evaporation of R50/R170 inside a horizontal tube by evaluating the mixture factor for that fluid.
- ❖ Comparisons of the present model and other classic models with the previous experimental data to evaluate the mean deviation for the hydrocarbon mixtures.

Contents

Experimental Apparatus



The Available Experimental Data for the Hydrocarbon Mixtures

The correlation is compared with a database of 738 data points of R50/R170.

The experiments were performed at eight compositions.

The flow boiling coefficients were measured in a 6 mm inner diameter cooper tube at saturation pressure of 0.35-0.65 MPa, heat flux of 10-60 kW/m², and mass flux of 113-260 kg/m²s.

The uncertainties of the heat transfer coefficients with the 95 % confidence interval range from 6.5 % to 17.2 % under the employed operation condition.

Details of the Proposed Correlation

The correlation by Zou (2010) was based on the asymptotic model (Liu et al., 1991) and developed by introducing a new mixture factor *K* from the reseach of pool boiling heat transfer of mixture.It is as follows:

$$h_{\mathrm{tp,m}} = \left(\left(E h_{\mathrm{sp}} \right)^2 + \left(K S h_{\mathrm{nb}} \right)^2 \right)^{0.5} \qquad (1)$$

where E is the forced convective heat transfer enhancement factor and h_{sp} is calculated from Dittus–Boelter equation; S is the suppression factor and h_{nb} is calculated from Cooper's pool boiling correlation.

$$h_{\mathrm{sp}} = 0.023 (Re_{\mathrm{l}})^{0.8} (Pr_{\mathrm{l}})^{0.4} \frac{k_{\mathrm{l}}}{d_{\mathrm{h}}} \qquad (2)$$

$$E = \left[1 + X Pr_{\mathrm{l}} \left(\rho_{\mathrm{l}} / \rho_{\mathrm{v}} - 1 \right) \right]^{0.35} \qquad (3)$$

$$h_{\mathrm{nb}} = 55 p_{\mathrm{r}}^{0.12} \left(-\log_{10} \left(p_{\mathrm{r}} \right) \right)^{-0.55} M^{-0.5} q^{0.67} \qquad (4)$$

$$S = \left(1 + 0.055 E^{0.1} Re_{\mathrm{l}}^{0.16} \right)^{-1} \qquad (5)$$

$$K = \frac{h_{\mathrm{m}}}{h_{\mathrm{i}}} = \frac{1}{1 + \frac{\Delta T_{\mathrm{db}}}{\Delta T_{\mathrm{id}}} \left| y - x \right|^{-0.29} \left(\frac{p}{10^5} \right)^{-0.9} \left[1 - 0.87 \exp\left(-\frac{q}{3 \times 10^5} \right) \right]} \qquad (6)$$

$$\Delta T_{\mathrm{id}} = \frac{q}{h_{\mathrm{i}}} \qquad (7)$$

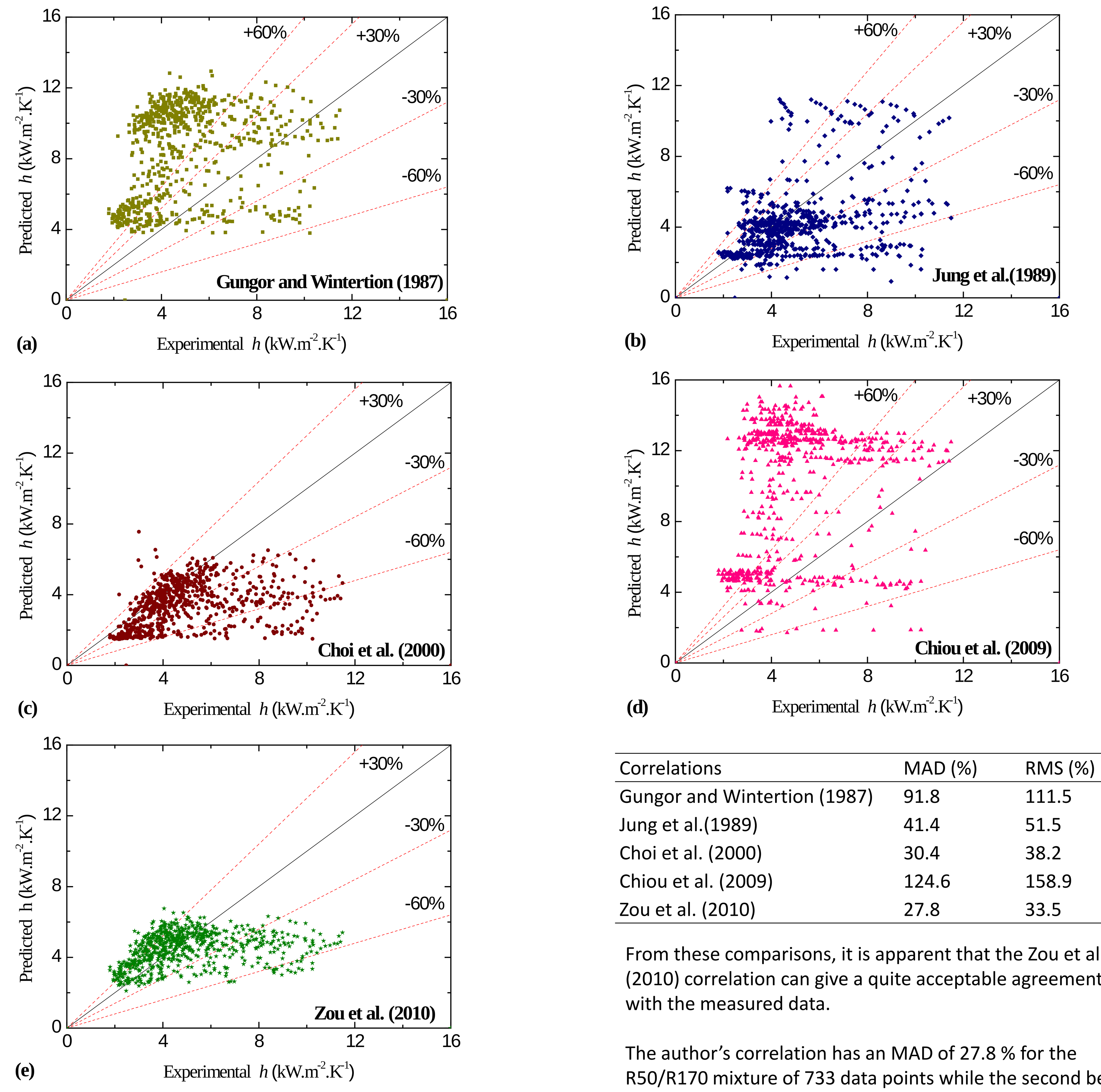
$$\Delta T_{\mathrm{db}} = T_{\mathrm{d}} - T_{\mathrm{b}} \qquad (8)$$

where ΔT_{id} is the ideal temperature difference and ΔT_{db} is the temperature difference between dew point and bubble point; P_r is the critical pressure and M is the molecular weight in equation (4).

Conclusions

- ❖ The correlation given by author's (Zou et al., 2010) shows very good agreement with 733 data points for the R50/R170 mixture.
- ❖ The author's correlation has an MAD of 27.8 % and an RMS of 33.5 % among the existing correlations.
- ❖ The author's correlation can be used to predict the flow boiling of hydrocarbon mixtures and LNG in some engineering applications.

Results



Correlations	MAD (%)	RMS (%)
Gungor and Wintertion (1987)	91.8	111.5
Jung et al.(1989)	41.4	51.5
Choi et al. (2000)	30.4	38.2
Chiou et al. (2009)	124.6	158.9
Zou et al. (2010)	27.8	33.5

From these comparisons, it is apparent that the Zou et al. (2010) correlation can give a quite acceptable agreement with the measured data.

The author's correlation has an MAD of 27.8 % for the R50/R170 mixture of 733 data points while the second best correlation has an MAD of 30.4 %.

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