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Heat Transfer of Refrigerant Mixtures

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ABSTRACT

Heat transfer coefficient correlations for single phase flow and evaporation and condensation of refrigerant mixtures have been developed based on experimental data for binary and ternary mixtures. A term has been included for the mass transfer resistance observed with mixtures during evaporation. The correlations have been used to predict heat transfer coefficients for proposed alternatives for HCFC-22.

INTRODUCTION

Heat transfer characteristics of binary mixtures have been studied by several researchers [1 - 15], with the general finding that mixture heat transfer coefficients are lower than the linear interpolation of pure component heat transfer coefficients. This is due to the effect of mixing on physical properties such as thermal conductivity, and the mass transfer resistance occuring during evaporation [12]. Correlations have been reported by Jung et al. [12, 13, 14] for calculating evaporation heat transfer coefficients of flowing binary mixtures. The purpose of this work was to develop correlations for heat transfer coefficients for single phase flow and evaporation and condensation of refrigerant mixtures, including higher multicomponent systems.

CORRELATIONS

Chen [2] suggested that two phase evaporative heat transfer coefficients can be predicted by adding the contributions of nucleate boiling and convective evaporation:

$$h(tp) = h(nb) + h(ce) \qquad (1)$$

This was extended by Jung [12], drawing from work by Stephan and Abdelsalam [4], Thome [7], and Unals [9] to include terms for the effect of mass transfer resistance of binary mixtures based on the difference in vapor and liquid concentrations. In the present work, the mass transfer resistance effect is also based on phase equilibrium data, but by use of phase temperature differences.

Gropp and Schlunder [10] and Saito and Hihara [15] have reported methods for relating mixture mass transfer resistance to phase temperature differences. We have chosen the method of Gropp and Schlunder, combining with Jung's correlation for the local two phase evaporative heat transfer coefficient for pure components:

$$h(tp) = Nh(sa) + F(p)h(lo) \qquad (2)$$

As described in Jung's report, N is the nucleate boiling factor which is a function of the Boiling number and the Martinelli parameter, h(sa) is the Stephan and Abdelsalam correlation [4], F(p) is the two phase enhancement factor determined from experimental data by Jung, and h(lo) is the Dittus-Boelter equation modified for quality by the term G(1-x) which is mass flux times (1 - quality).

Gropp and Schlunder [10] included the effect of mass transfer resistance of mixtures by using a correction factor based on the loss of driving force between the wall and actual mixture phase temperature as illustrated in Figure 1. Their mixture equation can be represented by:

$$h(m) = \frac{h(id)}{1 + [h(id)/q][T(i) - T(s)]} \qquad (3)$$

where h(m) is the mixture heat transfer coefficient, h(id) is the heat transfer coefficient of a mixture with no mass transfer resistance effects, q is the heat flux, T(i) is the temperature at the vapor-liquid interface, and T(s) is the saturation temperature. For h(id), we have chosen to use equation (2) with transport properties calculated for the subject mixture. Mixture transport properties are calculated based on methods similar to those recommended by Jung and Radermacher [16]. T(i) is calculated for each condition of phase equilibria based on the approach described by Gropp and Schlunder. Overall refrigerant-side heat transfer coefficients are determined by numerical integration of the local heat transfer coefficients.

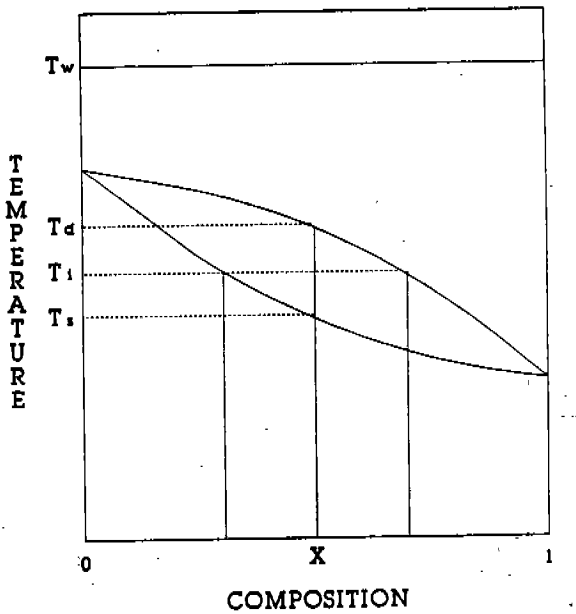

FIGURE 1

COMPARISON WITH EXPERIMENTAL DATA

A comparison of local heat transfer coefficients calculated from equation (3) with experimental data by Jung [12] is shown in Figure 2 for compositions of CFC-12 and HFC-152a. The largest deviation from Jung's data is 13% at 60 mole percent CFC-12, with values of 4% and 7% at 20 and 90 mole percent CFC-12. The data were taken at 65% quality in the convective evaporation region, and there was no special influence on the heat transfer coefficient at the azeotropic composition.

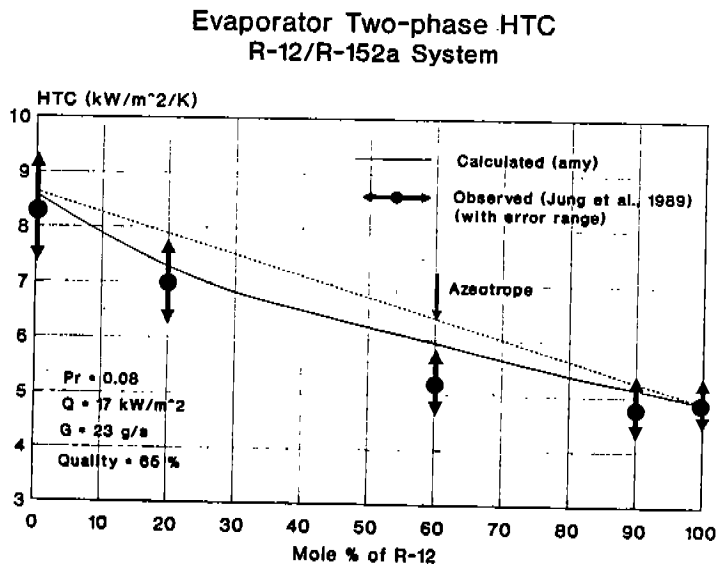

FIGURE 2

Experimental overall heat transfer coefficient data were available from Eckels and Pate [17] for a ternary mixture of HCFC-22, HFC-152a, and HCFC-124, which has the designation KCD-9433. The data were measured for evaporation temperatures of 5, 10, and 15 degrees C, mass flux range of 130 to 400 kg/m2/sec, and inlet and exit qualities of 10% and 85%, respectively. A comparison of overall evaporative heat transfer coefficients calculated from equation (3) with the data of Eckels and Pate are shown in Figure 3. The calculated values for the ternary mixture were 0 - 28% higher than the experimental data, with an average difference of 10.1%. The ternary mixture has a dew point/bubble point temperature difference of 4.0 degrees C (7.2 degrees F) at a pressure of 1290 kPa (187.1 psia).

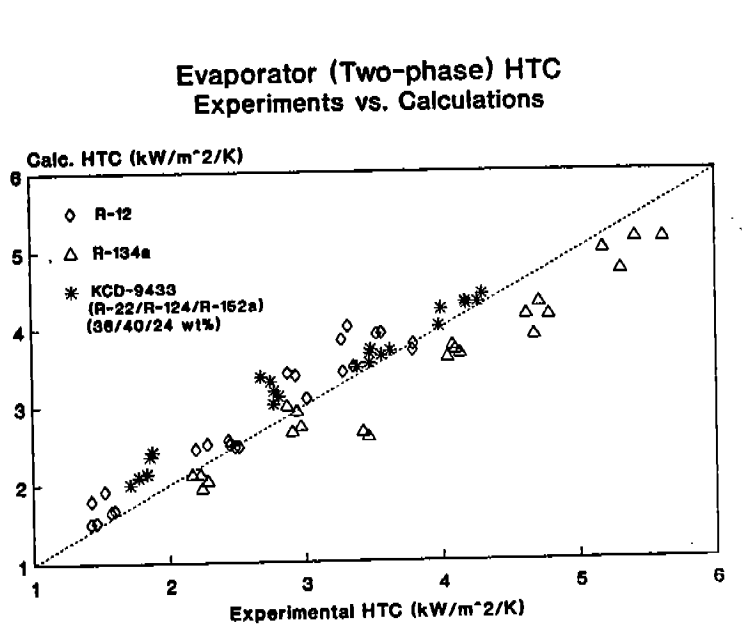

FIGURE 3

Also included in Figure 3 are overall evaporative heat transfer coefficients for single compounds CFC-12 and HFC-134a, calculated from a numerical integration of equation (2) and compared with data from Eckels and Pate. The fit of the data indicate similar agreement as was found with the ternary mixture.

Single phase liquid heat transfer coefficients were determined by Eckels and Pate for the ternary mixture and for CFC-12 and HFC-134a at 25 degrees C and mass fluxes ranging from 500 to 900 kg/m2/sec. Comparison of the experimental data with calculations using the Petukhov-Popov correlation [18], Figure 4, shows a maximum difference of 4%.

Ternary mixture two phase condensation heat transfer coefficients were calculated using the Cavallini-Zecchin equation [19] with no correction term for mixture mass transfer resistance. Comparisons were made with experimental data from Eckels and Pate for the mixture taken at condensation temperatures of 30, 40, and 50 degrees C, mass flux range of 130 to 400 kg/m2/sec, and inlet and exit qualities of 85% and 12%, respectively. Comparison data in Figure 5 show maximum differences of +13.5% and -10.0%, indicating no large effect of mass transfer resistance for the mixture having a temperature glide of 4.0 degrees C. For mixtures having more significant non azeotropic behavior, the temperature difference factor suggested by Saito and Hihara [15] could be investigated. Additional condensation heat transfer data for non azeotropic mixtures should be developed. Also shown in Figure 5 are comparison data for the single compounds CFC-12 and HFC-134a, indicating good agreement using the Cavallini-Zecchin equation.

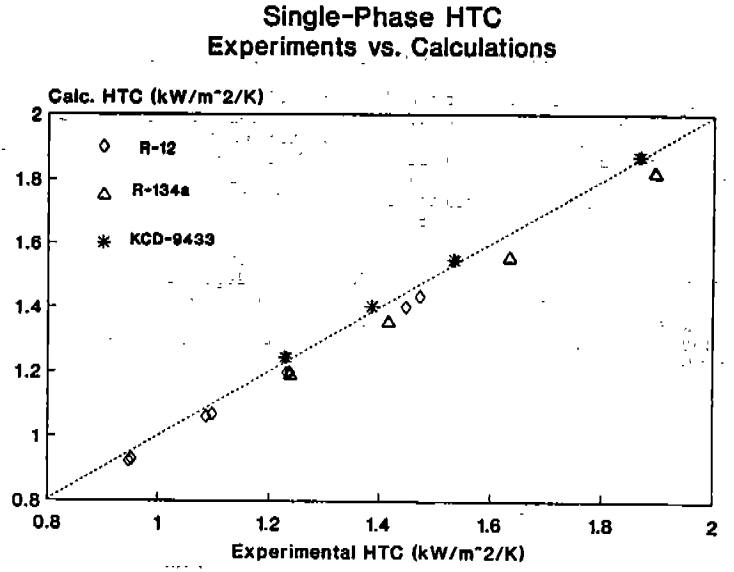

FIGURE 4

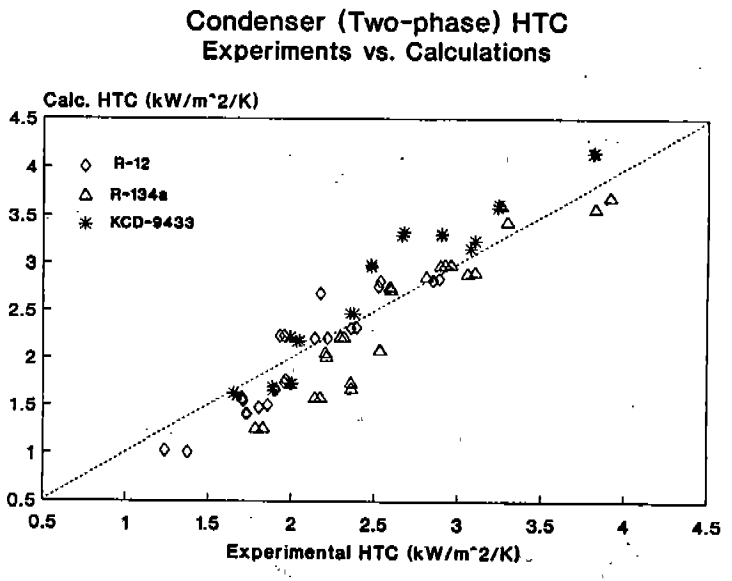

FIGURE 5

APPLICATION TO HCFC-22 ALTERNATIVES

The correlations described previously can be used to predict heat transfer coefficients of possible alternatives for HCFC-22. Alternatives nominated for the Air Conditioning and Refrigeration Institute study include mixtures of HFC-32/HFC-134a, HFC-32/HFC-125/HFC-134a, and HFC-32/HFC-125. Calculated heat transfer coefficients for these mixtures and HCFC-22 are shown in the following table for evaporation and condensation. Conditions used for the calculations were: 5.3 kW (1.5 ton) capacity air conditioner operating at 54.4 degrees C (130 F) condenser, 46.1 degrees C (115 F) liquid temperature, 7.2 degrees C (45 F) evaporator, 18.3 degrees C (65 F) return gas temperature, with tube inside diameter 6.2 mm (0.25 inch) for condenser and evaporator; the evaporator has three circuits of 7 m (23 ft.) length tubes.

CALCULATED HEAT TRANSFER COEFFICIENTS

	HCFC-22	32/134a 25/75	32/125/134a 30/10/60	32/125 60/40
Two Phase Heat Transfer Coefficient, W/m2/K				
Evaporator	5500	5400	5300	5800
Condenser	4500	5400	5400	5700

The calculated data indicate there should be no significant decrease in heat transfer coefficients in replacing HCFC-22 with the mixtures. The mixture temperature glides at the condenser conditions are 4.7 degrees C (8.5 degrees F) for the mixtures of HFC-32/HFC-134a and HFC-32/HFC-125/HFC-134a, and 0.1 degrees C (0.2 degrees F) for HFC-32/HFC-125.

CONCLUSIONS

Correlations for refrigerant mixture heat transfer coefficients for one phase flow and two phase flow evaporation and condensation have been developed and shown to have good agreement with experimental data. A term was used to account for the mixture evaporative mass transfer resistance based on the difference between liquid saturation temperature and liquid-vapor interface temperature. Additional data with non azeotropic mixtures having temperature glides greater than 5 degrees C are required to determine if a similar mass transfer resistance term is needed for condensation. The correlations can be used to calculate heat transfer coefficients of HCFC-22 alternative mixtures.

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