EXECUTIVE SUMMARY

FINAL REPORT ARTI-21CR/610-50010
PROPERTIES AND CYCLE PERFORMANCE OF REFRIGERANT BLENDS OPERATING NEAR AND ABOVE THE REFRIGERANT CRITICAL POINT – PART 1

This project has measured data and developed models for the properties of R410A and other HFC blends. An emphasis was placed on conditions near and above the mixture critical point—conditions where existing data were scarce and where a serious degradation in the performance of air-conditioning equipment has been observed. Many of the HFC blends have much lower critical temperatures than the CFCs or HCFCs (primarily R22) they are replacing, meaning that the operating temperatures of equipment using the blends can approach the critical temperature in extreme ambient conditions.

In this project the isochoric (constant volume) heat capacity of R125 was measured and a comprehensive, high-accuracy equation of state for the thermodynamic properties of this fluid was developed. R125 is a component of several important HFC blends, and improvements to the pure fluid formulation were a precursor to an improved mixture model. The isochoric heat capacity and pressure-density-temperature (P-ρ-T) behavior of R410A were measured and these data, along with data from the literature, were used to develop a new equation of state applicable to the entire class of HFC blends. Finally, measurements of the viscosity and thermal conductivity of R410A and R507A were carried out and the resulting data were compared to the mixture model in the NIST REFPROP database. R507A is the blend R125/143a (50/50); it is a replacement for R502. The R125/143a binary pair also comprises the majority of R404A, which is the blend R125/143a/134a (44/52/4).

In support of the R125 equation of state development, the isochoric heat capacity of R125 was measured over the temperature range 305 – 397 K (32 – 124 °C) at pressures up to 20 MPa. The measurements overlapped with existing data at lower temperatures and extended well above the R125 critical point of 339 K. These data are presented. A new formulation is presented for the thermodynamic properties of R125 based on both literature data and the new data measured in this project. This equation of state formulation is explicit in the Helmholtz energy and can be used for the calculation of all the thermodynamic properties, including density, heat capacity, speed of sound, enthalpy, entropy, and saturation properties. Ancillary equations are given for the ideal gas heat capacity, the vapor pressure, and for the saturated liquid and vapor densities. To minimize the number of terms, the equation was developed using new non-linear fitting techniques. Comparisons to the experimental data are given to establish the accuracy of properties calculated using the equation of state. The equation of state generally represents the experimental data within their uncertainties. The estimated uncertainties of calculated values are 0.1 % in density, 0.5 % in heat capacity, 0.02 % in speed of sound for the vapor at pressures less than 1 MPa, 0.5 % in the speed of sound elsewhere, and 0.1 % in vapor pressure. Deviations are higher in the critical region. The equation is valid for temperatures from the triple point temperature (172.52 K, –100.63 °C) to 500 K (227 °C) and pressures up to 60 MPa.

Measurements of the P-ρ-T behavior of R410A were completed along 14 isochores (lines of constant density) and covered the temperature range of 200 – 400 K (–73 to 127 °C) with pressures to 35 MPa. The isochoric heat capacity was measured along eight isochores with temperatures ranging from 303 to 397 K (30 to 124 °C) with pressures up to 18 MPa. These calorimetric measurements also provided simultaneous data of the P-ρ-T behavior. These data are presented.

Mixture models explicit in Helmholtz energy have been developed to calculate the thermodynamic properties of HFC refrigerant mixtures containing R32, R125, R134a, R143a, and/or R152a. The Helmholtz energy of the mixture is the sum of the ideal gas contribution, the compressibility (or real gas) contribution, and the contribution from mixing. The independent ii variables are the temperature, density, and composition. The model may be used to calculate all the thermodynamic properties of these mixtures, including dew and bubble point properties and critical points. It incorporates the most accurate equations of state for each pure fluid. The form of the model is the same for all the blends considered, but blend-specific mixing functions are required for the blends R32/125 (R410) and R32/134a (a constituent binary of R407). The systems R125/134a, R125/143a, R134a/143a, and R134a/152a share a common, generalized mixing function. The estimated uncertainties of calculated properties are 0.1% in density and 0.5% in heat capacities and the speed of sound. Calculated bubble point pressures are generally accurate to within 0.5%. The model is valid from 200 to 450 K (–73 to 177 °C) with pressures up to 60 MPa as verified by experimental data. The equation was developed primarily using data for binary (two-component) blends, but it is accurate in calculating the properties of the two mixtures with three constituents for which data were available. It is expected that this result will apply to other ternary and higher-order systems as well.

The new equation of state for R125 is believed to be the most accurate and comprehensive formulation for the properties of that fluid. Likewise, the mixture model developed in this work is the new state of the art for the thermodynamic properties of HFC blends. These models will be incorporated into version 7 of the NIST REFPROP database to be released in the summer of 2002.

Measurements of the viscosity and thermal conductivity of the HFC blends R410A and R507A were completed. The thermal conductivity measurements were carried out along six isotherms over the temperature range 301 to 404 K (28 to 131 °C) with pressures to 38 MPa. The measurements included liquid, vapor, and supercritical states. The viscosity was measured along five isotherms over the temperature range 301 to 421 K (28 to 148 °C) with pressures to 82 MPa. The originally planned viscosity measurements were also supplemented by measurements of the saturated liquid viscosity of R410A in a capillary viscometer over the range 288 to 320 K (15 to 47 °C). These data were used to assess the current models for the transport properties of mixtures. These comparisons reveal that further development and refinement of the transport models is warranted.