**PROPERTIES AND CYCLE PERFORMANCE OF REFRIGERANT BLENDS
OPERATING NEAR AND ABOVE THE REFRIGERANT CRITICAL POINT**

Task 1: Refrigerant Properties

Final Report

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Task 1. REFRIGERANT PROPERTIES

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EXECUTIVE SUMMARY

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

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.

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NOMENCLATURE

a	Helmholtz energy [J/mol]
C_v	heat capacity at constant volume [kJ/(kg-K)]
C_p	heat capacity at constant pressure [kJ/(kg-K)]
d, l, t	exponents in mixture model
f^*	resonant frequency [Hz]
F_{ij}	generalized mixture parameter
G	conductance [μ S]
i, j, l, m	exponents in equation of state
i, k	index for summation
n	number of components in mixture
N	numerical coefficient
p, P	pressure [MPa]
R	gas constant [8.314472 J/(mol-K)]
s	standard deviation in a measured quantity
T	temperature [K]
u	parameter in heat capacity (Equation 4)
x	mixture composition [mole fraction]
α	dimensionless Helmholtz energy ($\alpha = a/RT$)
β	exponent in Equation 6
δ	reduced density
Δ	difference between calculated and experimental quantity
Δf	bandwidth of resonance [Hz]
η	viscosity [mPa-s]
λ	thermal conductivity [W/m-K]
ρ	density [kg/m ³ (data); mol/L (equation of state)]
τ	inverse reduced temperature ($\tau = T_c/T$)
θ	dimensionless temperature ($\theta = 1 - T/T_c$)
ξ	density parameter in mixture model [L/mol]
ζ	temperature parameter in mixture model [K]

Note: Symbols used only once are defined where they occur.

Subscripts

c	critical point
calc	calculated value
exp	experimental value
liq	liquid
lit	value from literature
red	reduced
REFPROP	value calculated with the NIST REFPROP database
vap	vapor
σ	saturation
0	reference state (vacuum for viscosity measurements)

Superscripts

E	excess (departure from ideal mixing)
idmix	ideal mixing
r	residual or real-gas contribution
0	ideal gas state

1. INTRODUCTION

The Working Fluids Subcommittee of the ARTI 21-CR program has identified the performance of R410A at high ambient temperatures to be a very high research priority. This project has addressed the highest priority data needs. A parallel effort by the NIST Thermal Machinery Group under the direction of Dr. Piotr Domanski has investigated the cycle performance of blends operating near the refrigerant critical point and the modeling of cycles operating at such conditions. Further analysis of the performance was carried out by Dr. Keith Rice at Oak Ridge National Laboratory. Their work is detailed in companion reports. The work at NIST was jointly funded by the Air-Conditioning and Refrigeration Technology Institute (ARTI) under their 21-CR program, the Building Equipment Division of the U.S. Department of Energy, and the National Institute of Standards and Technology (NIST).

The 50/50 (by mass) blend of R32 and R125 is known as R410A. It is the replacement of choice for R22 in many heat pumps and air-conditioners. R404A is the blend of R125, R143a, and R134a at a composition of 44/52/4 mass percent; it is the replacement for R502 in many applications. Compared to R22, R410A and R404A operate at higher pressures and provide a greater refrigeration capacity. Both of these features stem from the lower critical temperatures of the blends. The critical temperatures of R410A (343 K or 70 °C) and R404A (345 K or 72 °C)] are significantly lower than the R22 critical temperature of 369 K or 96 °C. Or, stated differently, for a given ambient temperature, R410A and R404A operate closer to their respective critical temperatures than R22. At high ambient temperatures, the condensing temperature is near the critical temperature, and a significant energy penalty has been measured.

To understand the causes of the energy penalty at high ambient conditions, detailed modeling of the cycle is a valuable tool, and this requires reliable property data. But, there are very few data for the blends near their critical temperatures, and the limited data at lower temperatures indicates that present mixture models are not adequate.

To address the observed deficiencies in the existing mixture model, we have carried out measurements on R125 to fill in large gaps in the available data in the critical and supercritical regions (Task 1a). These data were used to develop an improved and comprehensive equation of state (Task 1b). Similar measurements on the blends (Task 1c), combined with the new R125 equation of state, were used to develop an improved mixture model for blends of R32, R125, R143a, R134a, and R152a (Task 1d). The results of this work have been incorporated into version 7 of the NIST REFPROP database [Lemmon et al. 2002], which will be released in the summer of 2002.

The focus of the properties work was on the thermodynamic properties and equation-of-state modeling, but we also addressed the transport properties of viscosity and thermal conductivity. Working from recent literature surveys (Yata, 1998 and Tanaka and Sotani, 1998) we identified key gaps in the available transport properties for the blends of interest and have measured those properties and compared them to the current model in REFPROP (Task 1e). The modeling of mixture transport properties was not part of the current project.

Fluid property data are important from at least three aspects. First, data impact the energy efficiency. A workable solution to replacing R22 could have been arrived at with only minimal data. But finding the fluid which will yield the best performance among many possibilities requires accurate data to distinguish small differences between fluids. Second, the design of refrigeration equipment increasingly involves the use of detailed simulation models. The results from such models can be no better than the reliability of the input data, of which, the fluid properties are among the most important. Third, the rating of compressors and other components requires property data to convert the raw temperature, pressure, and flow measurements from a

compressor calorimeter test into the efficiencies quoted on a product specification sheet. For this application, consensus is more important than absolute accuracy.

The project was composed of the following tasks. The results of each task are detailed in subsequent sections of this report.

Task 1a—R125 Heat Capacity Measurements

Measure the isochoric heat capacity (C_v) of R125 over the temperature range of 300 – 400 K with pressures extending from near saturation to 20 MPa. These measurements will be carried out along isochores (lines of constant density) with continuous scanning of the energy input and temperature rise.

Task 1b—R125 Equation of State Development

Collect R125 literature data for vapor pressure, saturated liquid density, P- ρ -T behavior, heat capacity, and speed of sound. Using the literature data together with the data measured in Task 1a, develop a comprehensive, high-accuracy equation of state for the thermodynamic properties of R125. The temperature range will extend from the triple point temperature of 172.52 K to at least 450 K, with pressures to 40 MPa. Incorporate this equation into the NIST REFPROP database.

Task 1c—Mixture P- ρ -T and Heat Capacity Measurements

Measure the pressure-density-temperature (P- ρ -T) behavior of R410A [R32/125 (50/50)] over the temperature range of 200 – 400 K with pressures extending from near saturation to 35 MPa. These measurements will be carried out along isochores with 5 – 10 data points per isochore, depending on the density.

Measure the isochoric heat capacity (C_v) of R410A [R32/125 (50/50)] over the temperature range of 300 – 400 K with pressures extending from near saturation to 20 MPa. These measurements will be carried out along isochores with continuous scanning of the energy input and temperature rise.

Task 1d—Mixture Modeling

Collect literature data for dew and bubble point pressures, saturated liquid density, P- ρ -T behavior, heat capacity, and speed of sound for HFC mixtures, including R32/125, R125/143a, R125/134a, R143a/134a, R32/134a, and R134a/152a. Using the literature data together with the data measured in Task 1c, develop a comprehensive, high-accuracy mixture model for the thermodynamic properties of HFC blends. The temperature range will extend from 200 K to at least 400 K, with pressures to 35 MPa. Incorporate this model into the NIST REFPROP database.

Task 1e—Mixture Transport Property Measurements

For the R410A mixture [R32/125 (50/50)] and for the R507A mixture [R125/143a (50/50)] measure the viscosity and thermal conductivity along isotherms covering the temperature range 300 – 400 K with pressures to 30 MPa. Approximately 20 data points per isotherm will be measured. Compare these data to the present mixture model in the NIST REFPROP database.

2. R125 HEAT CAPACITY MEASUREMENTS

Background. At the outset of the project, we suspected that deficiencies in the pure fluid R125 equation of state may have been at least partly responsible for the deviations seen with the R32/125 mixtures. (Mixture properties can be no better than the constituent pure fluids.) All of the R125-containing mixtures for which we have heat capacity data show higher deviations with our mixture model than those which do not contain R125. There was no reason to suspect that R125 would present any particular difficulties in this regards.

There was an enormous gap in the existing pure-fluid data for R125 in the vicinity of the critical point for any sort of thermal properties (i.e. C_v , C_p , enthalpy, or speed of sound). There are three or four individual data points for C_v above the R125 critical temperature of 339 K, but they are at much higher pressures (about 20 MPa versus the critical pressure of 3.6 MPa). There are a few liquid-phase speed of sound measurements, but those are at sub-critical temperatures and pressures at least double the critical pressure. There are vapor-phase speed of sound data that extend to 400 K (i.e. 61 K above the critical temperature), but the maximum pressure for these is 1 MPa—much lower than the critical pressure. It is our experience that heat capacity data is absolutely required to develop an adequate equation of state. This is especially so in the critical region.

For these reasons, the project included measurements of the heat capacity which extended well above critical and overlapped with existing data. These data were applied to the development of the R125 equation of state described in the next section. The large deviations seen with the old mixture model for the R32/125 mixtures were found to be largely a result of the peculiar behavior of R32, as detailed in Section 5, but nonetheless, a much-improved equation of state has resulted for this important fluid.

Experimental. The R125 used in this work was “electronic grade” material supplied by the Dupont Company¹. The analysis provided by the manufacturer stated a purity of 99.997 % with a water content less than 5 ppm. Our analysis by gas chromatography confirmed that it was of very high purity apart from a small (0.02 %) amount of air in the vapor phase. The air and any other light inorganics which may have been present were removed by repeatedly freezing the sample in liquid nitrogen, evacuating the vapor space, and thawing.

Measurements of the heat capacity of R125 were carried out using a constant-volume adiabatic calorimeter. The calorimeter has twin cells of constant volume that are operated in a differential manner. The heat required to raise the temperature of the cell containing the sample is measured relative to that required for a matched cell that is evacuated. Such an approach cancels some of the parasitic heat flows which can compromise the accuracy of the measurement. The supply gas was condensed (single phase) into the measurement cell at temperatures near 220 K and subsequently pressurized by warming. At the end of each isochore, a portion of the sample was carefully condensed into an external weighing cylinder that was cooled with liquid nitrogen. The weight change measured between each isochore and the final weight of the sample remaining in the cell after the last isochore provide the mass of the sample in the cell for each isochore. The high-temperature isochoric calorimeter was used to measure the isochoric specific heat (C_v) of pure R125. The apparatus and procedures are detailed by Magee et al. (1998).

The measurements cover the temperature region from 305 to 397 K along 7 isochores (lines of constant density) from 584 to 1202 kg/m³ with pressures up to 20 MPa. Repetitions of several of

¹ Suppliers are identified to fully document the details of the work. Mention of any supplier does not imply endorsement by NIST nor does it imply that the material is necessarily the best suited for the purpose.

the isochores were also carried out. The loci of the measured points on pressure-temperature coordinates are shown in Figure 1. The data themselves are given in Table 1. A comparison of these data to the R125 equation of state is given in the manuscript describing the equation (Appendix A of this report).

Figure 1. Isochoric heat capacity data for R125. The symbols indicate measured C_v data points and the line indicates the vapor pressure.

Table 1. Isochoric heat capacity data measured for R125.

T (K)	P (MPa)	C _v (kJ/kg-K)	T (K)	P (MPa)	C _v (kJ/kg-K)
305.5	5.418	0.8280	326.0	5.571	0.8668
306.0	5.635	0.8410	327.0	5.878	0.8700
306.5	5.851	0.8378	328.0	6.181	0.8741
307.0	6.067	0.8351	329.0	6.486	0.8704
308.0	6.498	0.8318	330.0	6.798	0.8735
309.0	6.933	0.8312	331.0	7.108	0.8747
310.0	7.365	0.8293	332.0	7.413	0.8739
311.0	7.797	0.8317	333.0	7.721	0.8766
312.0	8.230	0.8371	334.0	8.034	0.8740
313.0	8.665	0.8331	335.0	8.344	0.8737
314.0	9.098	0.8375	336.0	8.650	0.8697
315.0	9.531	0.8355	337.0	8.962	0.8720
316.0	9.964	0.8343	338.0	9.275	0.8723
317.0	10.399	0.8356	339.0	9.586	0.8736
318.0	10.833	0.8345	340.0	9.895	0.8779
319.0	11.267	0.8367	341.0	10.207	0.8759
320.0	11.700	0.8365	342.0	10.521	0.8747
321.0	12.135	0.8380	343.0	10.833	0.8732
322.0	12.569	0.8365	344.0	11.145	0.8773
323.0	13.004	0.8389	345.0	11.457	0.8765
324.0	13.436	0.8380	346.0	11.769	0.8754
325.0	13.871	0.8388	347.0	12.083	0.8773
326.0	14.305	0.8425	348.0	12.395	0.8763
327.0	14.740	0.8399	349.0	12.708	0.8788
320.5	11.939	0.8592	350.0	13.020	0.8821
321.0	12.156	0.8514	351.0	13.335	0.8828
321.5	12.372	0.8536	352.0	13.649	0.8825
322.0	12.592	0.8540	353.0	13.963	0.8804
323.0	13.027	0.8539	354.0	14.277	0.8832
324.0	13.461	0.8544	355.0	14.592	0.8823
325.0	13.895	0.8559	356.0	14.904	0.8822
326.0	14.332	0.8559	357.0	15.220	0.8842
327.0	14.766	0.8563	358.0	15.536	0.8853
328.0	15.201	0.8610			
329.0	15.634	0.8572	321.5	4.197	0.8537
330.0	16.069	0.8629	322.0	4.347	0.8614
331.0	16.507	0.8641	322.5	4.501	0.8685
332.0	16.942	0.8650	323.0	4.655	0.8676
333.0	17.373	0.8649	324.0	4.957	0.8668
334.0	17.807	0.8597	325.0	5.261	0.8697
335.0	18.245	0.8627	326.0	5.570	0.8679
336.0	18.680	0.8632	327.0	5.875	0.8660
337.0	19.114	0.8691	328.0	6.181	0.8709
			329.0	6.488	0.8667
321.5	4.198	0.8845	330.0	6.799	0.8712
322.0	4.349	0.8795	331.0	7.104	0.8719
322.5	4.503	0.8817	332.0	7.414	0.8704
323.0	4.656	0.8775	333.0	7.720	0.8680
324.0	4.959	0.8686	334.0	8.032	0.8633
325.0	5.261	0.8691	335.0	8.344	0.8720

Table 1. C_v for R125 (continued)

T (K)	P (MPa)	C_v (kJ/kg-K)	T (K)	P (MPa)	C_v (kJ/kg-K)
336.0	8.651	0.8698	344.0	6.869	0.9185
337.0	8.962	0.8735	345.0	7.101	0.8922
338.0	9.273	0.8747	346.0	7.334	0.8885
339.0	9.586	0.8692	347.0	7.570	0.8857
340.0	9.895	0.8737	348.0	7.804	0.8852
341.0	10.208	0.8751	349.0	8.037	0.8882
342.0	10.520	0.8723	350.0	8.273	0.8888
343.0	10.832	0.8740	351.0	8.509	0.8848
344.0	11.145	0.8747	352.0	8.745	0.8918
345.0	11.455	0.8724	353.0	8.981	0.8908
346.0	11.769	0.8758	354.0	9.216	0.8904
347.0	12.081	0.8776	355.0	9.454	0.8937
348.0	12.396	0.8786	356.0	9.691	0.8894
349.0	12.708	0.8840	357.0	9.929	0.8936
350.0	13.022	0.8808	358.0	10.164	0.8907
351.0	13.334	0.8822	359.0	10.405	0.8917
352.0	13.651	0.8851	360.0	10.642	0.8944
353.0	13.964	0.8817	361.0	10.880	0.8886
354.0	14.276	0.8831	362.0	11.116	0.8927
355.0	14.590	0.8832	363.0	11.358	0.8869
356.0	14.907	0.8847	364.0	11.598	0.8939
357.0	15.221	0.8854	365.0	11.834	0.8935
358.0	15.533	0.8899	366.0	12.072	0.8943
359.0	15.847	0.8883	367.0	12.313	0.9003
360.0	16.163	0.8855	368.0	12.554	0.8930
361.0	16.478	0.8907	369.0	12.793	0.9015
362.0	16.792	0.8874	370.0	13.031	0.8971
363.0	17.104	0.8862	371.0	13.271	0.8978
364.0	17.421	0.8880	372.0	13.513	0.9032
365.0	17.736	0.8860	373.0	13.754	0.9008
366.0	18.049	0.8874	374.0	13.992	0.9051
367.0	18.361	0.8880	375.0	14.233	0.9060
368.0	18.679	0.8898	376.0	14.475	0.9008
369.0	18.994	0.8920	377.0	14.713	0.9008
370.0	19.305	0.8885	378.0	14.955	0.9013
			379.0	15.197	0.9233
331.5	4.003	0.9279	380.0	15.437	0.9241
332.0	4.114	0.8952	381.0	15.675	0.9242
332.5	4.228	0.8912	382.0	15.916	0.9275
333.0	4.341	0.8898	383.0	16.160	0.9094
334.0	4.567	0.8801	384.0	16.401	0.9192
335.0	4.794	0.8911	385.0	16.640	0.9196
336.0	5.023	0.8917	386.0	16.879	0.9197
337.0	5.249	0.8858	387.0	17.122	0.9175
338.0	5.479	0.8896	388.0	17.366	0.9279
339.0	5.711	0.8890	389.0	17.607	0.9353
340.0	5.941	0.9061	390.0	17.846	0.9295
341.0	6.170	0.9359	391.0	18.086	0.9328
342.0	6.403	0.9352	392.0	18.330	0.9290
343.0	6.637	0.9391	393.0	18.572	0.9291

Table 1. C_v for R125 (continued)

T (K)	P (MPa)	C_v (kJ/kg-K)	T (K)	P (MPa)	C_v (kJ/kg-K)
394.0	18.812	0.9452	375.0	14.235	0.9151
395.0	19.050	0.9418	376.0	14.475	0.9164
396.0	19.294	0.9452	377.0	14.716	0.9116
397.0	19.536	0.9578	378.0	14.956	0.9145
			379.0	15.197	0.9132
331.5	4.002	0.9288	380.0	15.439	0.9158
332.0	4.117	0.9134	381.0	15.679	0.9190
332.5	4.229	0.9060	382.0	15.919	0.9183
333.0	4.342	0.8985	383.0	16.160	0.9181
334.0	4.568	0.8932	384.0	16.402	0.9223
335.0	4.797	0.8940	385.0	16.643	0.9217
336.0	5.024	0.8924	386.0	16.883	0.9245
337.0	5.251	0.8934	387.0	17.125	0.9285
338.0	5.482	0.8933	388.0	17.366	0.9237
339.0	5.713	0.8903	389.0	17.608	0.9269
340.0	5.942	0.8909	390.0	17.848	0.9268
341.0	6.172	0.8902	391.0	18.091	0.9270
342.0	6.405	0.8864	392.0	18.332	0.9320
343.0	6.637	0.8871	393.0	18.573	0.9294
344.0	6.870	0.8900	394.0	18.814	0.9301
345.0	7.101	0.8925	395.0	19.055	0.9323
346.0	7.336	0.8925	396.0	19.297	0.9322
347.0	7.570	0.8990	397.0	19.538	0.9343
348.0	7.805	0.8952			
349.0	8.039	0.8981	338.5	4.150	0.9487
350.0	8.274	0.8997	339.0	4.237	0.9414
351.0	8.512	0.8972	339.5	4.324	0.9414
352.0	8.746	0.8980	340.0	4.412	0.9314
353.0	8.983	0.8977	341.0	4.584	0.9189
354.0	9.218	0.8931	342.0	4.760	0.9202
355.0	9.456	0.8963	343.0	4.936	0.9128
356.0	9.693	0.8999	344.0	5.113	0.9192
357.0	9.931	0.9001	345.0	5.288	0.9221
358.0	10.168	0.9045	346.0	5.466	0.9123
359.0	10.404	0.8992	347.0	5.644	0.9126
360.0	10.644	0.8989	348.0	5.825	0.9155
361.0	10.882	0.9005	349.0	6.005	0.9136
362.0	11.120	0.9005	350.0	6.183	0.9111
363.0	11.357	0.9032	351.0	6.363	0.9195
364.0	11.597	0.9070	352.0	6.546	0.9175
365.0	11.836	0.9065	353.0	6.728	0.9178
366.0	12.075	0.9090	354.0	6.909	0.9248
367.0	12.316	0.9131	355.0	7.093	0.9201
368.0	12.555	0.9115	356.0	7.276	0.9155
369.0	12.794	0.9137	357.0	7.458	0.9123
370.0	13.033	0.9080	358.0	7.640	0.9079
371.0	13.274	0.9082	359.0	7.825	0.9103
372.0	13.514	0.9093	360.0	8.010	0.9118
373.0	13.754	0.9127	361.0	8.193	0.9228
374.0	13.993	0.9161	362.0	8.377	0.9253

Table 1. C_v for R125 (continued)

T (K)	P (MPa)	C_v (kJ/kg-K)	T (K)	P (MPa)	C_v (kJ/kg-K)
363.0	8.563	0.9226	358.0	6.187	0.9504
364.0	8.750	0.9228	359.0	6.325	0.9360
365.0	8.936	0.9161	360.0	6.463	0.9363
366.0	9.121	0.9156	361.0	6.598	0.9290
367.0	9.307	0.9183	362.0	6.736	0.9190
368.0	9.494	0.9164	363.0	6.875	0.9545
369.0	9.679	0.9196	364.0	7.013	0.9502
370.0	9.864	0.9193	365.0	7.149	0.9547
371.0	10.052	0.9216	366.0	7.288	0.9626
372.0	10.239	0.9255	367.0	7.427	0.9255
373.0	10.425	0.9264	368.0	7.568	0.9335
374.0	10.612	0.9266	369.0	7.705	0.9349
375.0	10.799	0.9243	370.0	7.846	0.9328
376.0	10.988	0.9234	371.0	7.984	0.9324
377.0	11.176	0.9264	372.0	8.126	0.9282
378.0	11.364	0.9296	373.0	8.265	0.9333
379.0	11.552	0.9341	374.0	8.407	0.9385
380.0	11.742	0.9384	375.0	8.544	0.9342
381.0	11.930	0.9374	376.0	8.686	0.9378
382.0	12.118	0.9416	377.0	8.828	0.9436
383.0	12.308	0.9348	378.0	8.967	0.9329
384.0	12.497	0.9404	379.0	9.107	0.9468
385.0	12.685	0.9385	380.0	9.251	0.9471
386.0	12.874	0.9348	381.0	9.393	0.9402
387.0	13.062	0.9394	382.0	9.532	0.9446
388.0	13.253	0.9380	383.0	9.675	0.9399
389.0	13.440	0.9388	384.0	9.816	0.9367
390.0	13.630	0.9401	385.0	9.956	0.9354
391.0	13.819	0.9436	386.0	10.099	0.9445
392.0	14.010	0.9383	387.0	10.241	0.9453
393.0	14.196	0.9385	388.0	10.382	0.9533
394.0	14.387	0.9445	389.0	10.521	0.9535
395.0	14.577	0.9444	390.0	10.666	0.9501
396.0	14.768	0.9455	391.0	10.807	0.9520
397.0	14.956	0.9470	392.0	10.950	0.9457
			393.0	11.091	0.9506
345.5	4.514	0.8882	394.0	11.234	0.9480
346.0	4.581	0.9390	395.0	11.377	0.9446
346.5	4.647	0.9508	396.0	11.520	0.9507
347.0	4.713	0.9533	397.0	11.662	0.9513
348.0	4.843	0.9716			
349.0	4.976	0.9531	344.5	4.160	1.1976
350.0	5.109	0.9459	345.0	4.212	1.1144
351.0	5.241	0.9340	345.5	4.265	1.0867
352.0	5.377	0.9389	346.0	4.318	1.0693
353.0	5.511	0.9444	347.0	4.425	1.0433
354.0	5.643	0.9277	348.0	4.531	1.0530
355.0	5.779	0.9484	349.0	4.637	1.0421
356.0	5.917	0.9377	350.0	4.743	1.0290
357.0	6.053	0.9331	351.0	4.851	1.0022

Table 1. C_v for R125 (continued)

T (K)	P (MPa)	C_v (kJ/kg-K)	T (K)	P (MPa)	C_v (kJ/kg-K)
352.0	4.960	0.9784	394.0	9.659	0.9579
353.0	5.069	0.9902	395.0	9.773	0.9523
354.0	5.178	0.9930	396.0	9.888	0.9563
355.0	5.286	0.9877	397.0	10.001	0.9540
356.0	5.396	0.9835			
357.0	5.506	0.9564	344.5	4.051	1.2455
358.0	5.615	0.9498	345.0	4.093	1.2273
359.0	5.723	0.9367	345.5	4.136	1.2251
360.0	5.835	0.9491	346.0	4.178	1.2140
361.0	5.944	0.9603	347.0	4.262	1.1640
362.0	6.053	0.9523	348.0	4.346	1.1357
363.0	6.164	0.9744	349.0	4.432	1.1129
364.0	6.274	0.9535	350.0	4.517	1.0834
365.0	6.387	0.9593	351.0	4.601	1.0653
366.0	6.495	0.9492	352.0	4.686	1.0457
367.0	6.610	0.9546	353.0	4.773	1.0463
368.0	6.720	0.9606	354.0	4.859	1.0468
369.0	6.833	0.9456	355.0	4.945	1.0567
370.0	6.943	0.9642	356.0	5.030	1.0468
371.0	7.057	0.9424	357.0	5.117	1.0231
372.0	7.170	0.9475	358.0	5.203	1.0022
373.0	7.280	0.9395	359.0	5.289	0.9934
374.0	7.394	0.9460	360.0	5.374	0.9937
375.0	7.505	0.9438	361.0	5.460	0.9892
376.0	7.620	0.9493	362.0	5.547	0.9880
377.0	7.731	0.9653	363.0	5.633	0.9967
378.0	7.844	0.9440	364.0	5.719	1.0069
379.0	7.956	0.9563	365.0	5.804	0.9816
380.0	8.071	0.9532	366.0	5.891	0.9833
381.0	8.183	0.9487	367.0	5.978	0.9791
382.0	8.296	0.9639	368.0	6.064	0.9651
383.0	8.409	0.9542	369.0	6.148	0.9680
384.0	8.523	0.9516	370.0	6.235	0.9625
385.0	8.635	0.9528	371.0	6.321	0.9598
386.0	8.749	0.9505	372.0	6.407	0.9635
387.0	8.863	0.9595	373.0	6.492	0.9731
388.0	8.977	0.9600	374.0	6.579	0.9737
389.0	9.090	0.9549	375.0	6.665	0.9721
390.0	9.203	0.9530	376.0	6.752	0.9730
391.0	9.318	0.9539	377.0	6.839	0.9722
392.0	9.432	0.9551			
393.0	9.545	0.9564			

3. R125 EQUATION OF STATE

The available literature data for R125 include vapor pressure, saturated liquid and vapor densities, P- ρ -T behavior, heat capacity, virial coefficients, and speed of sound. These were combined with the data measured in Task 1a to fit an equation of state. A complete discussion of the equation of state, the available data, and comparisons of the data with the equation of state are given in a paper to be submitted for publication in the *Journal of Physical and Chemical Reference Data* (Lemmon and Jacobsen 2002a). The manuscript is included here as Appendix A. A summary of the equation follows.

The equation of state for R125 has been formulated using the Helmholtz energy as the fundamental property with independent variables of density and temperature. The equation of state is given by

$$a(\rho, T) = a^0(\rho, T) + a^r(\rho, T), \quad (1)$$

where a is the Helmholtz energy, $a^0(\rho, T)$ is the ideal gas contribution to the Helmholtz energy, and $a^r(\rho, T)$ is the residual Helmholtz energy. All thermodynamic properties can be calculated as derivatives of the Helmholtz energy. The functional form used for the new equation for R125 is explicit in the dimensionless Helmholtz energy, α , using independent variables of dimensionless density and temperature. The form of this equation is

$$\frac{a(\rho, T)}{RT} = \alpha(\delta, \tau) = \alpha^0(\delta, \tau) + \alpha^r(\delta, \tau), \quad (2)$$

where $\delta = \rho / \rho_c$, $\tau = T_c / T$, the critical temperature (T_c) is 339.173 K and the critical density (ρ_c) is 4.779 mol/L. The ideal gas Helmholtz energy is given in a dimensionless form by

$$\alpha^0 = \frac{h_0^0 \tau}{RT_c} - \frac{s_0^0}{R} - 1 + \ln \left(\frac{\delta \tau_0}{\delta_0 \tau} \right) - \frac{\tau}{R} \int_{\tau_0}^{\tau} \frac{c_p^0}{\tau^2} d\tau + \frac{1}{R} \int_{\tau_0}^{\tau} \frac{c_p^0}{\tau} d\tau, \quad (3)$$

where $\delta_0 = \rho_0 / \rho_c$, $\tau_0 = T_c / T_0$, and ρ_0 and T_0 are the density and temperature of the reference state. The equation for the ideal gas heat capacity for R125 is given by

$$\frac{c_p^0}{R} = 3.063T^{0.1} + 2.303 \frac{u_1^2 \exp(u_1)}{[\exp(u_1) - 1]^2} + 5.086 \frac{u_2^2 \exp(u_2)}{[\exp(u_2) - 1]^2} + 7.3 \frac{u_3^2 \exp(u_3)}{[\exp(u_3) - 1]^2}, \quad (4)$$

where u_1 is 314 K/T, u_2 is 756 K/T, u_3 is 1707 K/T and the gas constant, R , is 8.314472 J/(mol·K).

The functional form for the residual Helmholtz energy for R125 is

$$\alpha^r(\delta, \tau) = \sum_{k=1}^5 N_k \delta^{i_k} \tau^{j_k} + \sum_{k=6}^{15} N_k \delta^{i_k} \tau^{j_k} \exp(-\delta^{l_k}) + \sum_{k=16}^{18} N_k \delta^{i_k} \tau^{j_k} \exp(-\delta^{l_k}) \exp(-\tau^{m_k}), \quad (5)$$

where the coefficients and exponents are given in Table 2. The final three terms of the equation of state contain an exponential in temperature in addition to the usual density exponential. These terms, combined with theoretical constraints on the values of the exponents, result in an improved fit of the data with a minimum number of terms, as detailed in Appendix A. This represents a significant advance in the art of equations of state.

The critical temperature and density for the equation of state were obtained by fitting saturation data at temperatures above 324 K to the equation

$$\frac{\rho_{\sigma}}{\rho_c} - 1 = N_1 \left[1 - \frac{T_{\sigma}}{T_c} \right] \pm N_2 \left[1 - \frac{T_{\sigma}}{T_c} \right]^{\beta}, \quad (6)$$

where $N_1 = 0.98136$, $N_2 = 1.9125$, $\beta = 0.33414$, T_{σ} is the saturation temperature, and ρ_{σ} is the saturation density for the liquid or the vapor. The critical density and critical temperature were fitted simultaneously with the coefficients of the equation. This equation is only valid in the critical region.

The vapor pressure can be represented with the ancillary equation

$$\ln \left(\frac{p_{\sigma}}{p_c} \right) = \frac{T_c}{T} [N_1 \theta + N_2 \theta^{1.5} + N_3 \theta^{2.3} + N_4 \theta^{4.6}], \quad (7)$$

where $N_1 = -7.5295$, $N_2 = 1.9026$, $N_3 = -2.2966$, $N_4 = -3.4480$, $\theta = (1 - T/T_c)$, and p_{σ} is the vapor pressure. The critical pressure was determined from the equation of state at the critical temperature and density.

The resulting values of the critical temperature and density and the value of the critical pressure obtained in fitting the vapor pressure ancillary equation are

$$T_c = 339.173 \text{ K},$$

$$\rho_c = 4.779 \text{ mol/L, and}$$

$$p_c = 3.6177 \text{ MPa.}$$

These values should be used for all property calculations using the equation of state.

The saturated liquid density is represented by the ancillary equation

$$\frac{\rho'}{\rho_c} = 1 + N_1 \theta^{1/3} + N_2 \theta^{0.6} + N_3 \theta^{2.9}, \quad (8)$$

where ρ' is the saturated liquid density, $N_1 = 1.6684$, $N_2 = 0.88415$, and $N_3 = 0.44383$.

The saturated vapor density is represented by

$$\ln \left(\frac{\rho''}{\rho_c} \right) = N_1 \theta^{0.38} + N_2 \theta^{1.22} + N_3 \theta^{3.3} + N_4 \theta^{6.9}, \quad (9)$$

where ρ'' is the saturated vapor density, $N_1 = -2.8403$, $N_2 = -7.2738$, $N_3 = -21.890$, and $N_4 = -58.825$. Values calculated from the equation of state using the Maxwell criteria were used in developing this equation, and deviations between the equation of state and the ancillary equation are generally less than 0.03% below 337.5 K and less than 0.3% elsewhere.

The ancillary equations were helpful in the initial assessment of the data. They are presented here because they may be of utility when simple equations for the saturation boundary are needed. They are not required by the equation of state, however.

The new equation of state describes the thermodynamic surface with an uncertainty of 0.1% in density at temperatures from the triple point (172.52 K) to 500 K and pressures up to 60 MPa. In the gaseous and supercritical region, speed of sound data are represented within 0.01% at pressures below 1 MPa. The estimated uncertainty for heat capacities is 0.5% and the estimated uncertainty for the speed of sound in the liquid phase is 0.5%. The saturation values can be calculated from the equation of state by application of the Maxwell criterion, which requires equal Gibbs energies and equal pressures for saturated liquid and vapor states at the same temperature. The estimated uncertainties of vapor pressures and saturated liquid densities calculated using the Maxwell criterion are 0.1% for each property, except in the critical region, and the estimated uncertainty for saturated vapor density is 0.2%.

Table 2. Coefficients and exponents to the R125 equation of state.

k	N_k	i_k	j_k	l_k	m_k
1	5.280760	1	0.669		
2	-8.676580	1	1.05		
3	0.7501127	1	2.75		
4	0.7590023	2	0.956		
5	0.01451899	4	1.00		
6	4.777189	1	2.00	1	
7	-3.330988	1	2.75	1	
8	3.775673	2	2.38	1	
9	-2.290919	2	3.37	1	
10	0.8888268	3	3.47	1	
11	-0.6234864	4	2.63	1	
12	-0.04127263	5	3.45	1	
13	-0.08455389	1	0.72	2	
14	-0.1308752	5	4.23	2	
15	0.008344962	1	0.20	3	
16	-1.532005	2	4.5	2	1.7
17	-0.05883649	3	29.0	3	7.0
18	0.02296658	5	24.0	3	6.0

4. MIXTURE P- ρ -T AND HEAT CAPACITY MEASUREMENTS

Background. The data gaps for R410A are much more severe than those for R125. The single existing heat capacity data set for R32/125 contains only a few data points near the critical temperature, but at pressures significantly above the critical pressure. Furthermore, these data are for the 30/70 mass percent mixture. There are no heat capacity data for the 50/50 composition of R410A. There are several P- ρ -T data sets for R32/125, but again much of the data are for the 30/70 mass percent mixture. P- ρ -T data are the most important data in developing a mixture model, and thus, the temperature range of the P- ρ -T measurements is wider than the C_v measurements. The lack of P- ρ -T data at the R410A composition is especially pronounced for higher densities, which are the most useful in modeling. The present measurements have filled in the existing data gaps and extended well above critical.

No new measurements of the thermodynamic properties for R404A were included. Our recent literature survey of data for HFC mixtures (McLinden *et al.* 1998, Lemmon and McLinden 2001) revealed a number of high-quality data sets for the R125/143a/134a system and its constituent binaries (R125/143a, R125/134a, and R143a/134a) including heat capacity measurements for two of the three constituent binaries. (The available mixture data are discussed in Appendix B.) While these data are not optimal with respect to the compositions measured and coverage in the vicinity of the critical point, our modeling approach (described in Section 5) will develop a generalized mixing function for the entire class of HFC mixtures. Given the greater importance of R410A, that is where we focused our efforts.

Experimental. Cylinders of the R410A mixture were prepared gravimetrically from high-purity components. The R32 and R125 used in this work were “electronic grade” materials supplied by the Dupont Company. The analysis provided by the manufacturer stated a minimum purity of 99.99 % with a water content less than 5 ppm. Our analysis by gas chromatography confirmed that it was of very high purity apart from a small amount of air in the vapor phase. The air and any other light inorganics which may have been present in the components were removed by repeatedly freezing the sample in liquid nitrogen, evacuating the vapor space, and thawing. The target compositions for the blend was 0.50/0.50 mass fraction. The actual composition of the first R410A (R32/125) cylinder was 0.50001/0.49999 mass fraction. The uncertainty in composition is ± 0.00002 mass fraction. This cylinder was used for the P- ρ -T and viscosity measurements.

An additional quantity of the R410A mixture was prepared gravimetrically from the same high-purity components and used for the heat capacity and thermal conductivity measurements. The actual composition of the second R410A (R32/125) sample was 0.49987/0.50013 mass fraction.

Measurements of the R410A P- ρ -T properties were completed along 14 isochores using an isochoric (constant volume) PVT apparatus. The central element of the apparatus is a measuring cell consisting of a copper cylinder containing a cavity of approximately 28.5 cm³; the exact volume has been determined by measurements on methane and nitrogen and is corrected for temperature and pressure effects. The temperature is changed in selected increments, and the pressure is measured after equilibrium is achieved at each temperature, until the upper limit of temperature or pressure is reached.

The mixture sample is handled at all times as a low pressure gas well below the dew point pressure so that condensation and potential composition shifts are avoided. It is loaded into the apparatus by evacuating and cooling the cell. The gaseous mixture flows through a fine-diameter capillary and condenses to a liquid only when entering the cell; thus any composition shifts on loading are avoided. The cell is subsequently pressurized by heating. At the end of each isochore, a portion of the sample is extracted as high-pressure, single-phase fluid and

collected in an external weighing cylinder cooled with liquid nitrogen. The weight change measured between each isochore and the final weight of the sample remaining in the cell after the last isochore provide the mass of the sample in the cell for each isochore. The volume of the sample cell together with these measured masses provide the density. The apparatus is described in detail by Magee (1996).

The P- ρ -T measurements cover the temperature range from 200 to 400 K with pressures up to 35 MPa. A special emphasis was placed on measurements near the critical state conditions, with extensive coverage of the supercritical region. The loci of the measured points on pressure-temperature coordinates are shown in Figure 2. The data themselves are given in Table 3. A comparison of these data to the mixture equation of state is given in the manuscript describing the mixture model (Appendix B of this report).

Measurements of the heat capacity of R410A were carried out using the constant-volume adiabatic calorimeter described in Section 2. For these measurements, the weight change measured between each isochore was analyzed to provide the density in addition to the heat capacity. The density and heat capacity were measured in temperature increments of 1 K along eight isochores (lines of constant volume) from the saturation temperature to near 400 K with pressures to near the upper limit pressure of the apparatus (20 MPa). Measurements on R410A were made at the temperatures and pressures shown in Figure 3. The data are given in Table 4. Good agreement was found between the fluid density measured for R410A with the calorimeter and the separate measurements made with the PVT apparatus in the region of overlap.

Figure 2. P- ρ -T (density) data for R410A. The symbols indicate measured P- ρ -T data points and the line indicates the bubble-point pressure.

Table 3. Pressure-density-temperature data measured for R410A.

T (K)	P (MPa)	ρ (kg/m ³)	T (K)	P (MPa)	ρ (kg/m ³)
200.001	4.169	1423.5	261.000	4.613	1233.6
201.000	5.649	1423.2	262.000	5.505	1233.4
202.001	7.188	1422.9	263.000	6.405	1233.2
203.001	8.749	1422.7	264.000	7.309	1233.0
204.000	10.314	1422.5	266.000	9.114	1232.7
206.001	13.460	1422.1	267.998	10.927	1232.4
208.000	16.606	1421.8	270.000	12.744	1232.2
210.000	19.749	1421.4	272.000	14.561	1231.9
212.000	22.887	1421.1	274.000	16.376	1231.7
214.000	26.017	1420.8	276.000	18.189	1231.4
216.000	29.136	1420.5	278.000	20.000	1231.2
218.000	32.244	1420.2	280.001	21.811	1230.9
220.000	35.345	1419.9	281.999	23.615	1230.7
200.000	4.150	1423.5	284.001	25.417	1230.4
			286.000	27.221	1230.2
220.000	4.148	1364.7	288.000	29.020	1230.0
221.000	5.419	1364.3	290.000	30.815	1229.8
221.999	6.711	1364.1	292.000	32.607	1229.5
223.001	8.024	1363.9	294.000	34.394	1229.3
224.002	9.344	1363.7			
226.001	11.989	1363.3	280.000	4.190	1160.9
227.998	14.636	1363.0	281.000	4.907	1160.7
230.000	17.284	1362.7	282.001	5.636	1160.5
232.001	19.926	1362.4	283.000	6.366	1160.4
234.000	22.565	1362.1	284.000	7.097	1160.2
236.001	25.199	1361.8	286.000	8.565	1159.9
238.000	27.825	1361.5	288.001	10.033	1159.7
240.001	30.445	1361.3	290.001	11.506	1159.4
242.001	33.058	1361.0	292.001	12.979	1159.2
			294.000	14.452	1159.0
240.002	4.203	1302.6	295.999	15.924	1158.7
241.000	5.274	1302.4	298.000	17.397	1158.5
242.000	6.364	1302.2	300.000	18.872	1158.3
243.000	7.462	1302.0	302.000	20.339	1158.1
244.000	8.558	1301.8	304.000	21.812	1157.9
246.000	10.771	1301.5	306.000	23.282	1157.6
248.000	12.980	1301.2	308.000	24.749	1157.4
250.000	15.199	1300.9	310.000	26.216	1157.2
252.000	17.412	1300.6	312.000	27.681	1157.0
254.000	19.618	1300.3	314.000	29.145	1156.8
256.000	21.823	1300.0	316.000	30.608	1156.6
258.000	24.027	1299.8	318.000	32.064	1156.4
260.000	26.223	1299.5	319.999	33.520	1156.2
262.000	28.415	1299.3	321.999	34.976	1156.0
264.000	30.603	1299.0			
266.000	32.787	1298.8			
268.000	34.963	1298.5			

Table 3. P- ρ -T for R410A (continued)

T (K)	P (MPa)	ρ (kg/m ³)	T (K)	P (MPa)	ρ (kg/m ³)
300.000	4.159	1073.1	324.001	4.139	927.8
301.000	4.721	1072.9	325.000	4.500	927.7
302.001	5.282	1072.8	325.999	4.865	927.6
302.999	5.848	1072.6	328.000	5.598	927.3
304.000	6.414	1072.5	330.000	6.334	927.1
306.001	7.551	1072.2	332.000	7.075	926.9
308.000	8.690	1072.0	335.999	8.564	926.6
310.001	9.835	1071.8	340.000	10.063	926.2
312.001	10.977	1071.6	343.999	11.570	925.9
314.001	12.123	1071.3	348.000	13.085	925.5
316.000	13.268	1071.1	351.999	14.603	925.2
318.000	14.413	1070.9	356.000	16.127	924.9
320.000	15.560	1070.7	360.000	17.654	924.5
324.000	17.842	1070.4	364.001	19.182	924.2
328.001	20.138	1070.0	368.001	20.715	923.9
332.000	22.434	1069.6	372.001	22.245	923.6
336.000	24.727	1069.2	376.000	23.778	923.3
339.999	27.017	1068.8	380.000	25.311	923.0
343.999	29.304	1068.5	384.001	26.843	922.6
348.000	31.589	1068.1	388.001	28.376	922.3
351.999	33.869	1067.7	392.000	29.906	922.0
			396.000	31.436	921.7
320.001	4.191	958.7	400.000	32.963	921.4
321.000	4.591	958.6			
322.001	4.992	958.4	327.999	4.072	891.0
323.000	5.393	958.3	329.000	4.395	890.9
324.001	5.796	958.2	330.000	4.719	890.8
325.999	6.606	958.0	331.000	5.046	890.6
328.000	7.420	957.8	332.001	5.372	890.5
332.000	9.053	957.4	333.999	6.029	890.3
336.000	10.696	957.0	336.001	6.690	890.2
339.999	12.347	956.7	338.000	7.359	890.0
343.999	14.003	956.3	339.999	8.023	889.8
348.000	15.663	956.0	344.000	9.366	889.5
352.000	17.326	955.7	347.999	10.719	889.1
356.001	18.994	955.3	351.999	12.079	888.8
360.000	20.662	955.0	356.001	13.444	888.5
364.000	22.330	954.7	359.999	14.816	888.2
368.001	23.999	954.3	364.001	16.190	887.9
372.000	25.667	954.0	368.000	17.569	887.6
376.000	27.336	953.7	372.000	18.949	887.3
380.000	29.002	953.3	376.000	20.331	887.0
384.000	30.668	953.0	380.001	21.715	886.7
388.000	32.333	952.7	384.000	23.100	886.4
392.001	33.994	952.3	388.000	24.486	886.1
			392.001	25.871	885.7
			395.999	27.255	885.4
			400.000	28.641	885.1

Table 3. P- ρ -T for R410A (continued)

T (K)	P (MPa)	ρ (kg/m ³)	T (K)	P (MPa)	ρ (kg/m ³)
333.001	4.203	840.7	344.999	5.018	625.3
334.000	4.477	840.6	346.000	5.162	625.3
335.000	4.755	840.5	347.999	5.454	625.2
336.000	5.032	840.4	349.999	5.752	625.1
338.000	5.592	840.2	352.000	6.054	624.9
340.001	6.157	840.0	356.000	6.668	624.7
344.001	7.297	839.7	360.000	7.292	624.5
348.000	8.451	839.4	364.001	7.922	624.3
351.998	9.614	839.1	368.000	8.560	624.1
356.000	10.785	838.8	372.000	9.202	623.9
360.000	11.964	838.5	376.000	9.847	623.7
364.000	13.148	838.2	380.001	10.497	623.4
367.999	14.338	837.9	384.001	11.149	623.2
372.000	15.532	837.6	387.999	11.804	623.0
376.001	16.727	837.3	392.000	12.460	622.8
380.000	17.928	837.0	396.000	13.118	622.6
384.000	19.129	836.7	400.000	13.778	622.4
388.000	20.332	836.5			
392.000	21.536	836.2			
396.001	22.741	835.9			
400.001	23.946	835.6			
339.000	4.584	767.8			
339.999	4.803	767.7			
342.000	5.245	767.6			
344.001	5.694	767.4			
348.001	6.604	767.1			
352.000	7.529	766.8			
356.000	8.466	766.5			
359.998	9.412	766.3			
364.001	10.366	766.0			
368.000	11.325	765.7			
372.001	12.290	765.5			
376.001	13.260	765.2			
380.000	14.235	765.0			
384.000	15.211	764.7			
388.000	16.190	764.4			
392.001	17.172	764.2			
396.000	18.155	763.9			
400.000	19.140	763.7

Figure 3. Isochoric heat capacity data for R410A. The symbols indicate measured C_v data points and the line indicates the bubble-point pressure. P- ρ -T (density) and C_v data were simultaneously measured at each point.

Table 4. Isochoric heat capacity and P- ρ -T data measured for R410A.

T (K)	P (MPa)	ρ (kg/m ³)	C_v (kJ/kg-K)	T (K)	P (MPa)	ρ (kg/m ³)	C_v (kJ/kg-K)
303.0	5.537	1070.8	0.931	342.0	12.139	944.5	0.943
304.0	6.101	1070.7	0.932				
305.0	6.664	1070.6	0.930	325.0	5.448	946.2	0.976
306.0	7.228	1070.4	0.932	325.5	5.642	946.1	0.970
307.0	7.791	1070.3	0.933	326.0	5.837	946.1	0.975
308.0	8.355	1070.2	0.929	327.0	6.228	946.0	0.963
309.0	8.920	1070.0	0.933	328.0	6.618	945.9	0.970
310.0	9.485	1069.9	0.931	329.0	7.007	945.8	0.972
311.0	10.049	1069.8	0.929	330.0	7.400	945.7	0.969
312.0	10.612	1069.6	0.928	331.0	7.793	945.6	0.971
313.0	11.179	1069.5	0.925	332.0	8.184	945.5	0.969
314.0	11.744	1069.4	0.925	333.0	8.577	945.4	0.968
315.0	12.310	1069.2	0.923	334.0	8.971	945.3	0.966
300.5	4.133	1071.2	0.931	335.0	9.367	945.2	0.967
301.0	4.415	1071.1	0.931	336.0	9.761	945.1	0.968
301.5	4.696	1071.0	0.930	337.0	10.156	945.0	0.968
302.0	4.978	1071.0	0.930	338.0	10.553	944.9	0.971
303.0	5.539	1070.8	0.927	339.0	10.950	944.8	0.967
304.0	6.102	1070.7	0.929	340.0	11.347	944.7	0.969
305.0	6.666	1070.6	0.930	341.0	11.743	944.6	0.971
306.0	7.230	1070.4	0.930	342.0	12.141	944.5	0.964
307.0	7.791	1070.3	0.931	343.0	12.539	944.4	0.962
308.0	8.355	1070.2	0.931	344.0	12.938	944.3	0.962
309.0	8.920	1070.0	0.931	345.0	13.334	944.3	0.954
310.0	9.486	1069.9	0.930	346.0	13.732	944.2	0.952
311.0	10.048	1069.8	0.930	347.0	14.132	944.1	0.957
312.0	10.612	1069.6	0.925	348.0	14.532	944.0	0.952
313.0	11.179	1069.5	0.921	349.0	14.930	943.9	0.953
314.0	11.746	1069.4	0.921	350.0	15.328	943.8	0.952
315.0	12.309	1069.2	0.915	351.0	15.729	943.7	0.947
				352.0	16.130	943.6	0.944
324.5	5.255	946.2	0.950	353.0	16.529	943.5	0.941
325.0	5.449	946.2	0.948	354.0	16.928	943.4	0.942
325.5	5.643	946.1	0.951	355.0	17.329	943.3	0.940
326.0	5.838	946.1	0.954	356.0	17.729	943.2	0.940
327.0	6.227	946.0	0.957	357.0	18.129	943.1	0.941
328.0	6.616	945.9	0.954				
329.0	7.006	945.8	0.954	338.0	6.180	859.9	0.996
330.0	7.400	945.7	0.956	339.0	6.484	859.8	1.000
331.0	7.793	945.6	0.955	340.0	6.784	859.8	0.994
332.0	8.184	945.5	0.955	341.0	7.085	859.7	0.994
333.0	8.576	945.4	0.951	342.0	7.390	859.6	0.989
334.0	8.972	945.3	0.948	343.0	7.697	859.5	0.987
335.0	9.368	945.2	0.952	344.0	8.000	859.5	0.993
336.0	9.762	945.1	0.953	345.0	8.305	859.4	0.989
337.0	10.156	945.0	0.950	346.0	8.612	859.3	0.987
338.0	10.552	944.9	0.948	347.0	8.920	859.2	0.986
339.0	10.950	944.8	0.944	348.0	9.228	859.2	0.982
340.0	11.346	944.7	0.942	349.0	9.535	859.1	0.986
341.0	11.742	944.6	0.947	350.0	9.844	859.0	0.985

Table 4. R410A C_v and P- ρ -T (continued)

T (K)	P (MPa)	ρ (kg/m ³)	C_v (kJ/kg-K)	T (K)	P (MPa)	ρ (kg/m ³)	C_v (kJ/kg-K)
351.0	10.153	858.9	0.981	367.0	10.898	759.9	0.975
352.0	10.463	858.9	0.983	368.0	11.136	759.9	0.973
353.0	10.773	858.8	0.976	369.0	11.372	759.8	0.979
354.0	11.082	858.7	0.977	370.0	11.607	759.8	0.979
355.0	11.393	858.6	0.976	371.0	11.844	759.7	0.980
356.0	11.705	858.5	0.977	372.0	12.082	759.7	0.980
357.0	12.016	858.5	0.976	373.0	12.319	759.6	0.975
358.0	12.327	858.4	0.972	374.0	12.557	759.5	0.982
359.0	12.640	858.3	0.972	375.0	12.795	759.5	0.979
360.0	12.955	858.2	0.963	376.0	13.034	759.4	0.975
361.0	13.266	858.2	0.963	377.0	13.271	759.4	0.980
362.0	13.579	858.1	0.956	378.0	13.510	759.3	0.975
363.0	13.892	858.0	0.948	379.0	13.749	759.2	0.977
364.0	14.208	857.9	0.951	380.0	13.989	759.2	0.981
365.0	14.521	857.9	0.941	381.0	14.227	759.1	0.984
366.0	14.834	857.8	0.942	382.0	14.466	759.1	0.985
367.0	15.149	857.7	0.947	383.0	14.707	759.0	0.988
368.0	15.465	857.6	0.944	384.0	14.946	758.9	0.992
369.0	15.779	857.6	0.952	385.0	15.186	758.9	0.988
370.0	16.093	857.5	0.951	386.0	15.424	758.8	0.986
371.0	16.407	857.4	0.946	387.0	15.667	758.8	0.983
372.0	16.724	857.3	0.950	388.0	15.907	758.7	0.979
373.0	17.039	857.3	0.947	389.0	16.146	758.6	0.979
374.0	17.354	857.2	0.951	390.0	16.386	758.6	0.981
375.0	17.669	857.1	0.955	391.0	16.628	758.5	0.980
376.0	17.987	857.0	0.953	392.0	16.869	758.5	0.978
377.0	18.302	856.9	0.960	393.0	17.108	758.4	0.979
				394.0	17.350	758.4	0.978
346.0	6.059	761.1	1.027	395.0	17.592	758.3	0.977
346.5	6.171	761.1	1.031	396.0	17.833	758.2	0.984
347.0	6.284	761.1	1.034	397.0	18.073	758.2	0.983
348.0	6.508	761.0	1.022				
349.0	6.732	761.0	1.021	350.0	5.722	615.0	1.178
350.0	6.958	760.9	1.009	351.0	5.869	615.0	1.145
351.0	7.186	760.9	1.004	352.0	6.016	614.9	1.133
352.0	7.412	760.8	0.993	353.0	6.163	614.9	1.095
353.0	7.641	760.7	0.998	354.0	6.311	614.9	1.090
354.0	7.871	760.7	0.999	355.0	6.462	614.9	1.064
355.0	8.101	760.6	0.992	356.0	6.613	614.8	1.048
356.0	8.331	760.6	0.995	357.0	6.762	614.8	1.044
357.0	8.564	760.5	0.988	358.0	6.914	614.8	1.050
358.0	8.794	760.5	0.980	359.0	7.065	614.7	1.012
359.0	9.028	760.4	0.981	360.0	7.218	614.7	1.011
360.0	9.260	760.4	0.981	361.0	7.370	614.7	1.016
361.0	9.493	760.3	0.981	362.0	7.523	614.6	0.989
362.0	9.725	760.2	0.982	363.0	7.675	614.6	1.005
363.0	9.960	760.2	0.979	364.0	7.830	614.6	1.004
364.0	10.195	760.1	0.980	365.0	7.985	614.5	1.000
365.0	10.429	760.1	0.975	366.0	8.138	614.5	1.006
366.0	10.663	760.0	0.972	367.0	8.294	614.5	1.014

Table 4. R410A C_v and P- ρ -T (continued)

T (K)	P (MPa)	ρ (kg/m ³)	C_v (kJ/kg-K)	T (K)	P (MPa)	ρ (kg/m ³)	C_v (kJ/kg-K)
368.0	8.450	614.4	1.012	371.0	8.462	571.0	1.035
369.0	8.605	614.4	1.010	372.0	8.600	570.9	1.032
370.0	8.761	614.4	1.008	373.0	8.738	570.9	1.029
371.0	8.918	614.3	0.996	374.0	8.878	570.9	1.018
372.0	9.075	614.3	0.997	375.0	9.018	570.8	1.022
373.0	9.230	614.2	0.985	376.0	9.157	570.8	1.026
374.0	9.387	614.2	0.987	377.0	9.296	570.8	1.036
375.0	9.544	614.2	0.987	378.0	9.435	570.7	1.031
376.0	9.703	614.1	0.992	379.0	9.576	570.7	1.027
377.0	9.859	614.1	1.001	380.0	9.716	570.7	1.025
378.0	10.016	614.1	0.995	381.0	9.856	570.6	1.018
379.0	10.175	614.0	1.004	382.0	9.996	570.6	1.031
380.0	10.334	614.0	0.996	383.0	10.137	570.6	1.028
381.0	10.491	613.9	1.001	384.0	10.277	570.5	1.028
382.0	10.649	613.9	1.011	385.0	10.417	570.5	1.033
383.0	10.808	613.9	1.001	386.0	10.559	570.5	1.031
384.0	10.967	613.8	1.006	387.0	10.699	570.4	1.033
385.0	11.125	613.8	1.005	388.0	10.841	570.4	1.043
386.0	11.285	613.7	1.004	389.0	10.981	570.4	1.043
387.0	11.443	613.7	1.005	390.0	11.122	570.3	1.036
388.0	11.602	613.7	1.009	391.0	11.263	570.3	1.040
389.0	11.762	613.6	1.011	392.0	11.406	570.3	1.033
390.0	11.921	613.6	1.006	393.0	11.546	570.2	1.033
391.0	12.080	613.5	1.016	394.0	11.688	570.2	1.048
392.0	12.241	613.5	1.011	395.0	11.830	570.2	1.040
393.0	12.401	613.5	1.008	396.0	11.972	570.1	1.042
394.0	12.559	613.4	1.016	397.0	12.112	570.1	1.044
395.0	12.720	613.4	1.008				
396.0	12.880	613.3	1.009	350.0	5.544	525.9	1.364
397.0	13.041	613.3	1.011	350.5	5.603	525.9	1.307
				351.0	5.663	525.9	1.332
352.0	5.879	571.5	1.317	352.0	5.780	525.8	1.288
353.0	6.011	571.4	1.260	353.0	5.898	525.8	1.232
354.0	6.143	571.4	1.200	354.0	6.017	525.8	1.233
355.0	6.277	571.4	1.183	355.0	6.137	525.8	1.160
356.0	6.411	571.4	1.151	356.0	6.256	525.8	1.168
357.0	6.545	571.3	1.135	357.0	6.376	525.8	1.149
358.0	6.679	571.3	1.131	358.0	6.496	525.8	1.129
359.0	6.814	571.3	1.106	359.0	6.617	525.7	1.129
360.0	6.950	571.3	1.104	360.0	6.738	525.7	1.118
361.0	7.085	571.2	1.089	361.0	6.858	525.7	1.102
362.0	7.221	571.2	1.092	362.0	6.980	525.7	1.095
363.0	7.358	571.2	1.090	363.0	7.101	525.7	1.084
364.0	7.496	571.2	1.087	364.0	7.223	525.7	1.072
365.0	7.632	571.1	1.076	365.0	7.344	525.6	1.075
366.0	7.769	571.1	1.065	366.0	7.465	525.6	1.059
367.0	7.908	571.1	1.062	367.0	7.587	525.6	1.067
368.0	8.047	571.1	1.040	368.0	7.709	525.6	1.054
369.0	8.183	571.0	1.040	369.0	7.831	525.5	1.054
370.0	8.323	571.0	1.043	370.0	7.953	525.5	1.058

Table 4. R410A C_v and P- ρ -T (continued)

T (K)	P (MPa)	ρ (kg/m ³)	C_v (kJ/kg-K)	T (K)	P (MPa)	ρ (kg/m ³)	C_v (kJ/kg-K)
371.0	8.076	525.5	1.045	377.0	8.361	475.6	1.057
372.0	8.199	525.5	1.058	378.0	8.468	475.5	1.064
373.0	8.321	525.4	1.038	379.0	8.576	475.5	1.057
374.0	8.444	525.4	1.043	380.0	8.683	475.5	1.062
375.0	8.567	525.4	1.039	381.0	8.790	475.5	1.070
376.0	8.691	525.4	1.035	382.0	8.898	475.4	1.066
377.0	8.813	525.3	1.042	383.0	9.005	475.4	1.063
378.0	8.937	525.3	1.037	384.0	9.112	475.4	1.065
379.0	9.060	525.3	1.043	385.0	9.219	475.4	1.057
380.0	9.184	525.3	1.042	386.0	9.326	475.4	1.055
381.0	9.306	525.2	1.038	387.0	9.434	475.3	1.062
382.0	9.431	525.2	1.050	388.0	9.541	475.3	1.058
383.0	9.555	525.2	1.045	389.0	9.648	475.3	1.058
384.0	9.680	525.1	1.051	390.0	9.754	475.2	1.066
385.0	9.802	525.1	1.051	391.0	9.863	475.2	1.064
386.0	9.926	525.1	1.032	392.0	9.970	475.2	1.069
387.0	10.050	525.0	1.030	393.0	10.077	475.2	1.074
388.0	10.175	525.0	1.027	394.0	10.185	475.1	1.077
389.0	10.299	525.0	1.039	395.0	10.292	475.1	1.075
390.0	10.422	525.0	1.042	396.0	10.400	475.1	1.075
391.0	10.546	524.9	1.053	397.0	10.507	475.1	1.072
392.0	10.671	524.9	1.050				
393.0	10.796	524.9	1.053				
394.0	10.919	524.8	1.058				
395.0	11.043	524.8	1.046				
396.0	11.168	524.8	1.046				
397.0	11.292	524.7	1.036				
355.0	6.015	475.9	1.159				
356.0	6.120	475.9	1.153				
357.0	6.225	475.9	1.163				
358.0	6.331	475.8	1.145				
359.0	6.438	475.8	1.105				
360.0	6.545	475.8	1.137				
361.0	6.651	475.8	1.128				
362.0	6.757	475.8	1.125				
363.0	6.864	475.8	1.122				
364.0	6.971	475.8	1.096				
365.0	7.077	475.8	1.102				
366.0	7.184	475.8	1.092				
367.0	7.291	475.8	1.091				
368.0	7.398	475.7	1.096				
369.0	7.505	475.7	1.094				
370.0	7.611	475.7	1.089				
371.0	7.718	475.7	1.075				
372.0	7.826	475.7	1.077				
373.0	7.933	475.7	1.073				
374.0	8.039	475.6	1.076				
375.0	8.146	475.6	1.085				
376.0	8.254	475.6	1.071				

5. MIXTURE MODEL

The mixture model developed here is based on corresponding states theory and uses reducing parameters which are dependent on the mole fraction of the mixture and critical point of the pure fluids to modify absolute values of density and temperature. This approach allows the thermodynamic values of the mixture to be based largely on the contributions from the pure fluids. Only the excess values, or the departure from ideal mixing, are required to accurately model the properties of the mixture.

In developing this model, an extensive collection of data, comprising more than 50,000 individual data points from more than 60 sources, was utilized. Data for the pressure-density-temperature (P- ρ -T) and vapor-liquid equilibria (VLE) behavior, speed of sound, heat capacity, and second virial coefficients for the blends R32/125, R32/134a, R125/134a, R125/143a, R143a/134a, R134a/152a, R32/125/134a, and R125/143a/134a were included. A complete discussion of the mixture model, the available data, and comparisons of the data with the model are given in a paper to be submitted for publication in the *Journal of Physical and Chemical Reference Data* (Lemmon and Jacobsen 2002b). The manuscript is included here as Appendix B. A summary of the model follows.

The model uses the Helmholtz energy as the basis for all calculations. The Helmholtz energy of the mixture is calculated as the sum of an ideal gas contribution, a real gas contribution, and a contribution from mixing. The Helmholtz energy for an ideal solution (the contributions of the ideal gas and real gas) is determined at the reduced density and temperature of the mixture using accurate pure fluid equations of state for the mixture components. Reducing parameters, dependent on the mole fraction, are used to modify values of density and temperature.

The contribution from mixing, a modified excess function, is given by an empirical equation. Three separate models (i.e. three separate excess functions) were developed to calculate the properties of the refrigerant mixtures studied in this work. The first two describe the properties of the binary mixtures R32/125 and R32/134a. The shape of the excess functions for these two mixtures differ from each other and from the other mixtures studied in this work, and cannot be modeled in a generalized fashion. However, the shapes of the excess functions for the mixtures R125/134a, R125/143a, R134a/143a, and R134a/152a were similar enough that one function could be developed that described the properties of all these systems. Additionally, experimental data for the ternary mixtures R32/125/134a and R125/134a/143a showed that no additional parameters would be required to model these multi-component mixtures.

The equation for the mixture Helmholtz energy used in this work is

$$a = a^{idmix} + a^E. \quad (10)$$

where the Helmholtz energy for an ideal mixture is

$$a^{idmix} = \sum_{i=1}^n x_i \left[a_i^0(\rho, T) + a_i^r(\delta, \tau) + RT \ln x_i \right], \quad (11)$$

and where ρ and T are the mixture density and temperature, δ and τ are the reduced mixture density and temperature, n is the number of components in the mixture, a_i^0 is the ideal gas Helmholtz energy of component i , a_i^r is the residual Helmholtz energy of component i , and the x_i are the mole fractions of the mixture constituents. The Helmholtz energies of the components are given by the pure-fluid equations of state listed in Table 5.

The reduced values of density and temperature used in Eq. (11) are

$$\delta = \rho / \rho_{red} \text{ and} \quad (12)$$

$$\tau = T_{red} / T, \quad (13)$$

where ρ and T are the mixture density and temperature, and ρ_{red} and T_{red} are the reducing values,

$$\rho_{red} = \left[\sum_{i=1}^n \frac{x_i}{\rho_{c_i}} + \sum_{i=1}^{n-1} \sum_{j=i+1}^n x_i x_j \xi_{ij} \right]^{-1} \text{ and} \quad (14)$$

$$T_{red} = \sum_{i=1}^n x_i T_{c_i} + \sum_{i=1}^{n-1} \sum_{j=i+1}^n x_i x_j \zeta_{ij}. \quad (15)$$

The parameters ζ_{ij} and ξ_{ij} are used to define the shapes of the reducing temperature and density curves, and they are determined simultaneously in the nonlinear fit of experimental data with the other parameters of the mixture model. These reducing parameters are not the same as the critical parameters of the mixture.

Three excess functions were developed for the mixtures studied in this work. The excess function for the mixture Helmholtz energy for these three models is expressed as

$$\frac{a^E}{RT} = \alpha^E(\delta, \tau, x) = \left\{ \sum_{i=1}^{n-1} \sum_{j=i+1}^n x_i x_j F_{ij} \right\} \sum_{k=1}^m N_k \delta^{d_k} \tau^{t_k} \exp(-\delta^{t_k}), \quad (16)$$

where the coefficients and exponents were obtained from nonlinear regression of experimental mixture data. Values of the parameters and coefficients for these equations are given in Tables 6 and 7.

A complete discussion of the calculation of mixture properties from the above equations is given in Appendix B.

Based on comparisons to experimental data, the estimated uncertainties of properties calculated with the mixture model 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. 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.

Table 5. Pure fluid equations of state for refrigerants used in the mixture model

Fluid	Author	Temperature Range (K)	Maximum Pressure (MPa)
R32	Tillner-Roth and Yokozeki (1997)	136.34 – 435	70
R125	Lemmon and Jacobsen (2002)	172.52 – 500	60
R134a	Tillner-Roth and Baehr (1994)	169.85 – 455	70
R143a	Lemmon and Jacobsen (2001)	161.34 – 650	100
R152a	Outcalt and McLinden (1996)	154.56 – 500	60

Table 6. Coefficients and exponents of the mixture equations

k	N_k	t_k	d_k	l_k
R32/125				
1	-0.0072955	4.50	2	1
2	0.078035	0.57	5	1
3	0.61007	1.90	1	2
4	0.64246	1.20	3	2
5	0.014965	0.50	9	2
6	-0.34049	2.60	2	3
7	0.085658	11.40	3	3
8	-0.064429	4.50	6	3
R32/134a				
1	0.22909	1.9	1	1
2	0.094074	0.25	3	1
3	0.00039876	0.07	8	1
4	0.021133	2.0	1	2
R125/134a, R125/143a, R134a/143a, R143a/152a				
1	-0.013073	7.4	1	1
2	0.018259	0.35	3	1
3	0.0000081299	10.0	11	2
4	0.0078496	5.3	2	3

Table 7. Parameters of the mixture equation

Binary Mixture	ζ_{ij} (K)	ξ_{ij} (L/mol)	F_{ij}
R32/125	28.95	-0.006008	1.0
R32/134a	7.909	-0.002039	1.0
R125/134a	-0.4326	-0.0003453	1.0
R125/143a	5.551	-0.0004452	1.1697
R134a/143a	2.324	0.0006182	0.5557
R134a/152a	4.202	0.004223	2.0

6. MIXTURE THERMAL CONDUCTIVITY MEASUREMENTS

Experimental. Cylinders of the R410A (R32/125) and R507A (R125/143a) mixtures were prepared gravimetrically from high-purity components. The R32 and R125 used in this work were “electronic grade” materials supplied by the Dupont Company. The manufacturer’s specification stated a minimum purity of 99.99 % with a water content less than 5 ppm. Our analysis by gas chromatography confirmed they were of very high purity apart from a small amount of air in the vapor phase. The R143a was refrigerant-grade material supplied by Honeywell; our analysis indicated a purity of 99.93 %. The air and any other light inorganics which may have been present in the components were removed by repeatedly freezing the sample in liquid nitrogen, evacuating the vapor space, and thawing. The target compositions for both blends were 0.50/0.50 mass fraction. The actual composition of the R507A (R125/143a) was 0.49983/0.50017 mass fraction. The “second” cylinder of R410A was used for the thermal conductivity measurements; its composition was 0.49987/0.50013 mass fraction. The uncertainty in compositions was ± 0.00002 mass fraction.

A transient hot-wire instrument was used to make measurements of the thermal conductivity of both R410A and R507A. Two anodized tantalum hot wires, with diameters of 25 μm , were immersed in the sample. They function as both electrical heat sources and resistance thermometers during the experiments. The anodized layer of tantalum pentoxide provides electrical insulation from the refrigerant sample. The low-pressure gas mixtures were condensed (single phase) into the measurement cell at temperatures near 220 K and subsequently pressurized to near 35 MPa by warming. The relative uncertainty, at 95 % confidence, of the thermal conductivity measurements is less than 1 % for most of the data, increasing to 3 % in the critical region where the fluid is very compressible and prone to convection. Transient measurements were made over the entire range of conditions and were supplemented by steady-state measurements of the low-density vapor at pressures below 3 MPa. The transient hot-wire technique and apparatus are described in detail by Perkins et al. (1991). The use of the transient apparatus in the steady-state mode is described by Roder et al. (2000).

The thermal conductivities of R410A and R507A were each measured along six isotherms from 300 to 400 K with pressures to 35 MPa. Three of the isotherms for each blend are supercritical. Over 634 measurements were made for R410A, and more than 687 data points were measured for R507A. Figures 4 and 5 depict the measured points on temperature-pressure coordinates.

Results. The thermal conductivity data for R410A and R507A are summarized in Figures 6 and 7, respectively. The experimental data are presented in Tables 8 – 11. These figures show that the thermal conductivity is a strong function of density and a somewhat weaker function of temperature. The critical enhancement is seen in the middle range of densities.

The present data are compared with the values calculated with the extended corresponding states model in REFPROP (Lemmon et al. 2002), which is the model of McLinden et al. (2000). This model is based only on the pure-fluid conductivities—there is no “mixture parameter” to account for interactions between dissimilar molecules. The need for such a mixture parameter is evident from examining the deviations between the present data and the model. The deviations for R410A (shown in Figure 8 and given in the data tables as $\Delta\lambda$) show a clear systematic deviation, which is especially pronounced at the higher densities. The largest deviations are seen for the isotherm at 360 K at densities near 500 kg/m^3 . These conditions are near the critical point, suggesting that the critical enhancement in the mixture model needs improvement. Systematic deviations are also seen for R507A (Figure 9), although here the model and data agree fairly well at high densities but show increasing deviations at the lower densities. There is little temperature dependence and deviations near the critical point are no higher than away from it.

Figure 4. Location of measured thermal conductivity data points for R410A

Figure 5. Location of measured thermal conductivity data points for R507A.

Figure 6. Thermal conductivity of R410A.

Figure 7. Thermal conductivity of R507A.

Figure 8. Deviations between the measured thermal conductivities for R410A and the model in REFPROP.

Figure 9. Deviations between the measured thermal conductivities for R507A and the model in REFPROP.

Table 8. Thermal conductivity for R410A measured by the steady-state technique. The column λ_{calc} gives values calculated by the NIST REFPROP database, and $\Delta\lambda$ is the difference between the experimental data and these calculated values.

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
361.489	0.902	23.17	0.01962	0.01867	5.09
361.671	0.903	23.17	0.01963	0.01869	5.05
361.894	0.903	23.15	0.01966	0.01871	5.10
361.526	0.626	15.76	0.01932	0.01866	3.53
361.716	0.626	15.74	0.01928	0.01868	3.22
361.962	0.625	15.71	0.01921	0.01870	2.72
362.201	0.625	15.70	0.01921	0.01872	2.61
362.443	0.626	15.70	0.01926	0.01874	2.75
361.577	0.319	7.87	0.01900	0.01866	1.83
361.770	0.320	7.88	0.01897	0.01868	1.57
362.236	0.319	7.85	0.01893	0.01872	1.13
362.526	0.320	7.86	0.01897	0.01874	1.20
361.790	0.206	5.03	0.01886	0.01868	0.98
362.023	0.206	5.03	0.01883	0.01870	0.71
362.274	0.207	5.05	0.01886	0.01872	0.75
362.531	0.206	5.04	0.01884	0.01874	0.51
361.304	0.208	5.09	0.01885	0.01863	1.17
361.515	0.209	5.10	0.01888	0.01865	1.22
361.744	0.209	5.11	0.01890	0.01867	1.22
362.006	0.208	5.08	0.01884	0.01870	0.77
362.260	0.208	5.08	0.01886	0.01872	0.75
361.325	0.108	2.63	0.01882	0.01863	1.00
361.522	0.108	2.61	0.01874	0.01865	0.47
361.765	0.108	2.62	0.01874	0.01867	0.35
362.010	0.108	2.63	0.01876	0.01870	0.34
381.340	0.710	16.90	0.02171	0.02051	5.87
381.574	0.710	16.89	0.02158	0.02053	5.12
381.792	0.710	16.86	0.02157	0.02055	4.97
382.052	0.709	16.84	0.02152	0.02057	4.60
382.304	0.710	16.85	0.02150	0.02060	4.38
381.391	0.540	12.72	0.02122	0.02051	3.48
381.636	0.540	12.72	0.02118	0.02053	3.16
381.885	0.540	12.71	0.02117	0.02055	3.00
382.146	0.541	12.71	0.02114	0.02058	2.72
382.387	0.540	12.70	0.02114	0.02060	2.61
381.266	0.416	9.75	0.02113	0.02049	3.11
381.494	0.416	9.72	0.02104	0.02051	2.56
381.736	0.415	9.71	0.02101	0.02054	2.30
381.974	0.416	9.72	0.02100	0.02056	2.14
382.240	0.417	9.73	0.02102	0.02059	2.11
381.525	0.211	4.89	0.02078	0.02052	1.29
381.768	0.212	4.89	0.02078	0.02054	1.17
382.013	0.211	4.87	0.02080	0.02056	1.15
382.280	0.210	4.86	0.02077	0.02059	0.88
381.127	0.109	2.52	0.02064	0.02048	0.80

Table 8. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
381.333	0.109	2.50	0.02059	0.02050	0.46
381.550	0.108	2.49	0.02057	0.02052	0.26
381.773	0.109	2.50	0.02057	0.02054	0.15
382.023	0.109	2.51	0.02059	0.02056	0.13
401.168	0.838	18.94	0.02375	0.02247	5.71
401.352	0.838	18.92	0.02358	0.02249	4.87
401.745	0.838	18.91	0.02355	0.02253	4.55
402.009	0.838	18.89	0.02353	0.02255	4.33
401.174	0.625	13.98	0.02351	0.02246	4.66
401.582	0.624	13.95	0.02337	0.02251	3.84
401.812	0.625	13.95	0.02343	0.02253	4.00
401.999	0.624	13.93	0.02336	0.02255	3.60
401.185	0.415	9.20	0.02328	0.02246	3.64
401.385	0.416	9.21	0.02326	0.02248	3.46
401.576	0.416	9.21	0.02318	0.02250	3.01
401.794	0.415	9.19	0.02314	0.02252	2.73
401.225	0.211	4.63	0.02309	0.02246	2.78
401.428	0.210	4.61	0.02292	0.02249	1.93
401.638	0.211	4.62	0.02295	0.02251	1.97
401.842	0.211	4.63	0.02300	0.02253	2.10
402.077	0.210	4.60	0.02296	0.02255	1.81
401.230	0.109	2.37	0.02278	0.02246	1.40
401.402	0.110	2.39	0.02268	0.02248	0.88
401.615	0.109	2.38	0.02274	0.02250	1.05
401.850	0.108	2.37	0.02270	0.02253	0.76
402.082	0.109	2.38	0.02274	0.02255	0.84

Table 9. Thermal conductivity for R410A measured by the transient hot-wire technique; data are listed in the order of measurement.

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
300.976	28.25	1191.0	0.10684	0.11756	-9.12
301.258	28.26	1190.2	0.10480	0.11744	-10.76
301.571	28.24	1189.3	0.10546	0.11728	-10.08
300.472	22.79	1172.7	0.10503	0.11376	-7.67
300.740	22.78	1171.8	0.10448	0.11362	-8.05
301.034	22.79	1170.9	0.10428	0.11349	-8.11
301.328	22.83	1170.2	0.10321	0.11337	-8.97
301.645	22.84	1169.3	0.10427	0.11324	-7.92
300.513	16.17	1144.3	0.10211	0.10836	-5.77
300.767	16.15	1143.3	0.10167	0.10821	-6.05
301.053	16.13	1142.3	0.10115	0.10806	-6.39
301.373	16.13	1141.2	0.09986	0.10789	-7.44
300.552	16.20	1144.3	0.10260	0.10836	-5.32
300.660	16.19	1143.9	0.10274	0.10830	-5.14
300.824	16.16	1143.2	0.10125	0.10820	-6.42
300.977	16.15	1142.6	0.10055	0.10811	-6.99
300.591	10.26	1112.8	0.10182	0.10288	-1.03
300.724	10.25	1112.2	0.09965	0.10280	-3.07
300.868	10.25	1111.7	0.09856	0.10272	-4.05
300.766	5.64	1080.7	0.09488	0.09787	-3.06
300.920	5.66	1080.2	0.09499	0.09780	-2.87
301.072	5.67	1079.5	0.09270	0.09772	-5.14
300.687	2.18	1050.1	0.09020	0.09357	-3.61
300.820	2.19	1049.4	0.08854	0.09350	-5.30
300.969	2.19	1048.7	0.08824	0.09341	-5.53
301.292	2.17	1046.6	0.08880	0.09317	-4.69
361.382	34.06	1041.7	0.08996	0.09814	-8.33
361.544	34.07	1041.3	0.08967	0.09809	-8.58
361.708	34.06	1040.7	0.08963	0.09802	-8.56
361.893	34.04	1040.1	0.08898	0.09794	-9.15
362.073	34.03	1039.5	0.08924	0.09788	-8.83
361.408	26.64	997.0	0.08383	0.09161	-8.49
361.572	26.66	996.6	0.08396	0.09156	-8.30
361.750	26.66	996.0	0.08315	0.09151	-9.13
361.932	26.65	995.3	0.08334	0.09143	-8.85
362.139	26.64	994.6	0.08285	0.09134	-9.30
361.434	20.48	947.4	0.07755	0.08533	-9.12
361.624	20.48	946.7	0.07745	0.08525	-9.15
361.821	20.49	946.0	0.07701	0.08519	-9.61
362.022	20.50	945.4	0.07704	0.08513	-9.50
362.221	20.51	944.6	0.07719	0.08505	-9.25
361.542	16.07	898.0	0.07212	0.08001	-9.86
361.730	16.07	897.1	0.07215	0.07992	-9.73
361.934	16.07	896.2	0.07170	0.07984	-10.20
362.152	16.08	895.3	0.07208	0.07976	-9.63
362.371	16.09	894.3	0.07211	0.07967	-9.49

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
361.241	12.73	846.3	0.06691	0.07533	-11.18
361.402	12.72	845.3	0.06675	0.07525	-11.29
361.605	12.72	844.0	0.06703	0.07514	-10.80
361.803	12.72	842.8	0.06701	0.07505	-10.71
362.009	12.73	841.6	0.06744	0.07496	-10.03
361.278	10.49	792.4	0.06282	0.07134	-11.94
361.464	10.50	791.0	0.06275	0.07124	-11.92
361.654	10.50	789.6	0.06269	0.07114	-11.88
361.863	10.49	787.9	0.06244	0.07102	-12.08
362.092	10.49	786.0	0.06319	0.07089	-10.86
360.975	9.01	740.2	0.06031	0.06823	-11.61
360.981	9.01	740.1	0.05994	0.06823	-12.15
361.145	9.02	738.5	0.06001	0.06813	-11.92
361.139	9.02	738.6	0.05974	0.06814	-12.33
361.309	9.02	736.9	0.05938	0.06804	-12.72
361.310	9.02	737.0	0.05924	0.06804	-12.93
361.493	9.02	735.1	0.05936	0.06793	-12.61
361.499	9.02	735.0	0.05947	0.06792	-12.45
361.703	9.02	732.9	0.05925	0.06780	-12.61
361.701	9.02	733.0	0.05921	0.06780	-12.67
360.844	8.10	689.0	0.05690	0.06587	-13.61
360.951	8.10	687.6	0.05743	0.06580	-12.71
360.957	8.10	687.5	0.05756	0.06579	-12.51
361.088	8.10	685.8	0.05723	0.06570	-12.90
361.093	8.11	685.7	0.05672	0.06570	-13.67
361.221	8.10	683.9	0.05676	0.06561	-13.49
361.227	8.10	683.7	0.05690	0.06560	-13.27
361.375	8.10	681.7	0.05673	0.06550	-13.39
361.381	8.10	681.6	0.05681	0.06549	-13.26
360.880	7.52	637.0	0.05524	0.06408	-13.79
360.874	7.52	637.1	0.05547	0.06408	-13.44
360.959	7.52	635.5	0.05463	0.06402	-14.66
360.968	7.53	635.4	0.05475	0.06401	-14.47
361.041	7.53	634.2	0.05534	0.06396	-13.48
361.050	7.53	634.1	0.05527	0.06395	-13.58
361.133	7.53	632.7	0.05540	0.06389	-13.29
361.140	7.53	632.6	0.05550	0.06389	-13.13
361.232	7.53	630.9	0.05516	0.06382	-13.56
361.236	7.53	630.7	0.05509	0.06381	-13.66
360.831	7.09	578.8	0.05352	0.06256	-14.46
360.831	7.10	578.9	0.05405	0.06257	-13.61
360.923	7.09	576.6	0.05331	0.06247	-14.66
360.925	7.09	576.5	0.05351	0.06247	-14.34
361.028	7.09	574.0	0.05333	0.06236	-14.48
361.020	7.09	574.2	0.05379	0.06237	-13.76
361.117	7.09	571.9	0.05395	0.06227	-13.36
361.101	7.09	572.3	0.05396	0.06229	-13.37

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
361.204	7.10	569.9	0.05374	0.06218	-13.57
361.208	7.10	569.9	0.05414	0.06218	-12.93
360.818	6.84	529.0	0.05256	0.06103	-13.87
360.824	6.84	528.7	0.05207	0.06101	-14.66
360.930	6.84	525.7	0.05193	0.06085	-14.65
360.921	6.84	526.0	0.05212	0.06086	-14.36
361.010	6.84	523.5	0.05169	0.06072	-14.87
361.008	6.84	523.6	0.05161	0.06072	-15.01
361.089	6.84	521.5	0.05237	0.06060	-13.58
361.108	6.84	521.1	0.05233	0.06057	-13.61
361.202	6.84	518.5	0.05229	0.06042	-13.46
361.203	6.84	518.6	0.05208	0.06042	-13.81
360.819	6.66	485.0	0.05077	0.05893	-13.85
360.838	6.66	484.5	0.05035	0.05889	-14.50
360.924	6.66	482.0	0.05009	0.05870	-14.67
360.937	6.66	481.6	0.05010	0.05867	-14.60
361.028	6.66	479.1	0.05031	0.05847	-13.96
361.037	6.66	478.9	0.05031	0.05845	-13.92
361.125	6.66	476.5	0.05057	0.05826	-13.20
361.110	6.67	477.0	0.05029	0.05830	-13.73
361.222	6.67	474.0	0.05052	0.05805	-12.97
361.219	6.67	474.2	0.05087	0.05806	-12.39
360.863	6.47	432.3	0.04722	0.05513	-14.34
360.871	6.47	432.1	0.04828	0.05511	-12.39
360.966	6.47	429.7	0.04730	0.05486	-13.77
360.982	6.47	429.3	0.04728	0.05481	-13.75
361.080	6.47	426.9	0.04761	0.05456	-12.74
361.094	6.47	426.6	0.04794	0.05453	-12.08
361.196	6.47	424.3	0.04770	0.05427	-12.11
361.168	6.47	425.0	0.04754	0.05435	-12.53
361.291	6.47	422.2	0.04750	0.05405	-12.11
361.283	6.47	422.5	0.04738	0.05408	-12.38
360.951	6.29	384.9	0.04348	0.05060	-14.06
360.955	6.29	384.9	0.04373	0.05059	-13.56
361.050	6.29	383.0	0.04364	0.05036	-13.34
361.075	6.29	382.5	0.04397	0.05029	-12.58
361.169	6.29	380.8	0.04401	0.05008	-12.11
361.175	6.29	380.7	0.04359	0.05006	-12.93
361.303	6.29	378.4	0.04399	0.04978	-11.63
361.300	6.29	378.6	0.04423	0.04979	-11.17
361.430	6.29	376.3	0.04392	0.04951	-11.28
361.415	6.29	376.6	0.04385	0.04955	-11.50
361.096	6.07	337.1	0.03949	0.04527	-12.77
361.104	6.07	337.1	0.03967	0.04527	-12.37
361.225	6.07	335.6	0.03961	0.04506	-12.09
361.235	6.07	335.5	0.03955	0.04505	-12.20
361.352	6.07	334.1	0.03991	0.04485	-11.01

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
361.362	6.07	334.0	0.03994	0.04484	-10.92
361.487	6.07	332.5	0.03958	0.04048	-2.23
361.487	6.07	332.5	0.03958	0.04463	-11.31
361.496	6.07	332.3	0.03936	0.04461	-11.77
361.639	6.07	330.5	0.03967	0.04436	-10.58
361.641	6.07	330.4	0.03975	0.04435	-10.38
361.290	5.79	289.7	0.03526	0.03966	-11.09
361.283	5.79	289.8	0.03548	0.03966	-10.55
361.440	5.79	288.4	0.03520	0.03947	-10.82
361.447	5.79	288.3	0.03508	0.03946	-11.09
361.602	5.79	287.0	0.03492	0.03928	-11.10
361.598	5.79	287.0	0.03498	0.03928	-10.95
361.763	5.79	285.7	0.03495	0.03910	-10.61
361.763	5.79	285.8	0.03504	0.03910	-10.39
361.938	5.79	284.5	0.03503	0.03892	-10.00
361.932	5.79	284.6	0.03504	0.03893	-10.00
361.448	5.39	240.2	0.03101	0.03387	-8.43
361.457	5.39	240.2	0.03108	0.03386	-8.22
361.613	5.39	239.5	0.03057	0.03377	-9.48
361.624	5.39	239.5	0.03075	0.03377	-8.94
361.796	5.39	238.7	0.03087	0.03367	-8.32
361.795	5.39	238.7	0.03071	0.03367	-8.80
361.978	5.39	237.9	0.03082	0.03357	-8.18
361.989	5.39	237.9	0.03066	0.03356	-8.65
362.187	5.39	237.0	0.03075	0.03345	-8.06
362.202	5.39	236.8	0.03065	0.03343	-8.30
361.791	4.79	187.7	0.02692	0.02829	-4.86
361.765	4.79	187.8	0.02700	0.02831	-4.61
362.009	4.79	187.2	0.02682	0.02824	-5.04
362.012	4.79	187.1	0.02683	0.02824	-5.00
362.247	4.79	186.4	0.02675	0.02817	-5.05
362.239	4.79	186.4	0.02674	0.02817	-5.07
362.474	4.79	185.8	0.02677	0.02811	-4.76
362.464	4.79	185.8	0.02681	0.02811	-4.62
362.710	4.79	185.2	0.02676	0.02805	-4.60
362.711	4.79	185.3	0.02674	0.02806	-4.70
362.139	4.03	139.6	0.02367	0.02410	-1.79
362.149	4.03	139.6	0.02362	0.02410	-2.01
362.390	4.03	139.3	0.02375	0.02409	-1.42
362.375	4.03	139.4	0.02367	0.02410	-1.76
362.642	4.03	139.0	0.02369	0.02408	-1.62
362.645	4.03	139.0	0.02362	0.02408	-1.90
362.939	4.03	138.5	0.02357	0.02405	-2.00
362.924	4.03	138.4	0.02365	0.02405	-1.65
363.226	4.03	138.0	0.02371	0.02403	-1.33
363.240	4.03	138.0	0.02371	0.02403	-1.32

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
316.449	29.89	1152.6	0.09860	0.11194	-11.92
316.795	29.88	1151.6	0.09857	0.11179	-11.83
317.142	29.84	1150.5	0.09869	0.11161	-11.58
315.892	22.08	1121.0	0.09406	0.10603	-11.29
316.164	22.08	1120.1	0.09510	0.10590	-10.20
316.478	22.10	1119.2	0.09367	0.10578	-11.45
316.832	22.12	1118.1	0.09389	0.10564	-11.12
317.183	22.13	1117.0	0.09362	0.10549	-11.25
315.940	15.71	1086.8	0.08952	0.10031	-10.76
316.229	15.70	1085.7	0.08908	0.10017	-11.07
316.540	15.70	1084.5	0.08870	0.10002	-11.31
316.896	15.72	1083.3	0.08858	0.09987	-11.30
317.248	15.74	1082.1	0.08897	0.09971	-10.77
316.012	11.17	1055.7	0.08508	0.09564	-11.05
316.216	11.15	1054.7	0.08504	0.09552	-10.98
316.440	11.15	1053.7	0.08478	0.09540	-11.14
316.685	11.15	1052.7	0.08408	0.09528	-11.76
316.919	11.17	1051.9	0.08441	0.09518	-11.32
316.055	7.47	1023.3	0.08098	0.09129	-11.29
316.264	7.49	1022.4	0.08053	0.09119	-11.69
316.480	7.50	1021.4	0.08079	0.09108	-11.30
316.737	7.48	1020.0	0.08031	0.09092	-11.66
316.994	7.47	1018.6	0.08064	0.09076	-11.15
316.093	4.66	990.4	0.07711	0.08738	-11.76
316.245	4.66	989.4	0.07791	0.08729	-10.74
316.411	4.66	988.4	0.07729	0.08718	-11.35
316.593	4.67	987.3	0.07683	0.08708	-11.77
316.773	4.68	986.4	0.07681	0.08698	-11.69
316.105	2.81	960.6	0.07480	0.08432	-11.29
316.265	2.81	959.5	0.07512	0.08422	-10.80
316.457	2.82	958.0	0.07475	0.08409	-11.11
316.634	2.82	956.7	0.07435	0.08398	-11.46
316.780	2.82	955.7	0.07476	0.08388	-10.87
381.680	30.09	955.9	0.08109	0.08792	-7.77
381.881	30.08	955.2	0.08059	0.08785	-8.26
382.064	30.08	954.6	0.08048	0.08779	-8.32
382.259	30.09	954.1	0.08040	0.08774	-8.36
382.485	30.10	953.5	0.08060	0.08768	-8.07
381.720	23.29	897.0	0.07433	0.08091	-8.14
381.932	23.28	896.1	0.07445	0.08083	-7.90
382.128	23.28	895.4	0.07408	0.08076	-8.28
382.358	23.29	894.6	0.07430	0.08069	-7.92
382.577	23.30	893.9	0.07422	0.08063	-7.95
381.603	18.97	845.1	0.06895	0.07568	-8.90
381.796	18.97	844.2	0.06918	0.07561	-8.51
382.005	18.96	843.2	0.06887	0.07552	-8.80
382.224	18.96	842.1	0.06912	0.07543	-8.37

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
382.454	18.96	841.1	0.06933	0.07534	-7.98
381.656	15.96	794.0	0.06450	0.07129	-9.52
381.873	15.95	792.7	0.06465	0.07118	-9.18
382.092	15.95	791.5	0.06461	0.07109	-9.11
382.326	15.95	790.2	0.06459	0.07099	-9.01
382.570	15.95	788.9	0.06488	0.07089	-8.48
381.765	13.69	739.5	0.06073	0.06725	-9.70
381.990	13.69	738.0	0.06061	0.06715	-9.73
382.226	13.69	736.5	0.06048	0.06703	-9.78
382.465	13.70	735.0	0.06050	0.06693	-9.61
382.726	13.70	733.5	0.06053	0.06682	-9.41
381.611	12.16	689.4	0.05792	0.06403	-9.54
381.614	12.16	689.5	0.05766	0.06403	-9.94
381.822	12.16	687.8	0.05749	0.06391	-10.05
381.829	12.15	687.6	0.05746	0.06391	-10.09
382.057	12.15	685.8	0.05723	0.06378	-10.28
382.055	12.15	685.9	0.05688	0.06378	-10.82
382.303	12.15	683.9	0.05726	0.06365	-10.05
382.307	12.15	683.9	0.05722	0.06365	-10.11
382.550	12.15	682.0	0.05716	0.06352	-10.02
382.565	12.15	681.9	0.05720	0.06352	-9.95
381.468	10.97	636.3	0.05447	0.06099	-10.70
381.466	10.97	636.5	0.05432	0.06100	-10.95
381.667	10.97	634.7	0.05442	0.06089	-10.62
381.666	10.97	634.8	0.05452	0.06089	-10.46
381.880	10.97	632.9	0.05447	0.06077	-10.37
381.890	10.97	632.9	0.05442	0.06077	-10.44
382.123	10.97	630.7	0.05388	0.06063	-11.13
382.128	10.97	630.6	0.05402	0.06062	-10.89
382.372	10.97	628.3	0.05427	0.06047	-10.26
382.387	10.97	628.1	0.05395	0.06046	-10.77
381.504	10.11	583.9	0.05198	0.05823	-10.73
381.513	10.12	583.9	0.05184	0.05823	-10.97
381.720	10.12	581.9	0.05187	0.05809	-10.71
381.725	10.12	581.9	0.05187	0.05809	-10.71
381.942	10.12	579.7	0.05168	0.05795	-10.82
381.943	10.12	579.8	0.05173	0.05795	-10.74
382.187	10.12	577.2	0.05136	0.05779	-11.13
382.194	10.12	577.1	0.05142	0.05778	-11.01
382.452	10.12	574.4	0.05137	0.05761	-10.83
382.465	10.12	574.3	0.05143	0.05760	-10.71
381.372	9.46	534.0	0.04979	0.05563	-10.49
381.364	9.46	534.1	0.04970	0.05563	-10.66
381.573	9.46	531.9	0.04962	0.05548	-10.56
381.575	9.46	532.0	0.04918	0.05548	-11.36
381.792	9.46	529.7	0.04906	0.05532	-11.32
381.796	9.46	529.7	0.04927	0.05532	-10.94

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
382.025	9.46	527.3	0.04901	0.05515	-11.14
382.047	9.46	527.1	0.04908	0.05514	-10.99
382.295	9.46	524.5	0.04897	0.05496	-10.89
382.295	9.46	524.5	0.04899	0.05496	-10.86
381.475	9.47	533.8	0.04964	0.05560	-10.71
381.479	9.47	533.7	0.04934	0.05559	-11.24
381.681	9.47	531.5	0.04932	0.05544	-11.04
381.687	9.46	531.4	0.04912	0.05543	-11.39
381.905	9.47	529.0	0.04919	0.05527	-11.00
381.911	9.47	529.1	0.04917	0.05527	-11.04
382.137	9.47	526.7	0.04891	0.05510	-11.24
382.134	9.47	526.8	0.04895	0.05511	-11.18
382.383	9.47	524.1	0.04880	0.05492	-11.15
382.389	9.47	524.1	0.04884	0.05492	-11.07
381.301	8.97	490.0	0.04688	0.05313	-11.76
381.300	8.97	490.0	0.04714	0.05313	-11.28
381.497	8.97	487.8	0.04715	0.05296	-10.97
381.511	8.97	487.5	0.04718	0.05294	-10.89
381.725	8.97	485.2	0.04655	0.05276	-11.78
381.739	8.97	485.0	0.04695	0.05275	-11.00
381.964	8.97	482.6	0.04655	0.05256	-11.44
381.953	8.97	482.7	0.04644	0.05257	-11.66
382.211	8.97	479.9	0.04654	0.05236	-11.11
382.200	8.97	480.2	0.04641	0.05237	-11.39
381.171	8.46	439.6	0.04397	0.04987	-11.83
381.174	8.46	439.6	0.04407	0.04987	-11.63
381.364	8.46	437.8	0.04414	0.04971	-11.20
381.365	8.46	437.8	0.04430	0.04971	-10.88
381.583	8.46	435.6	0.04377	0.04952	-11.61
381.585	8.46	435.5	0.04386	0.04951	-11.41
381.820	8.46	433.1	0.04380	0.04930	-11.16
381.822	8.46	433.1	0.04374	0.04930	-11.28
382.063	8.46	430.7	0.04390	0.04909	-10.58
382.053	8.46	430.8	0.04369	0.04910	-11.02
381.243	7.98	387.8	0.04094	0.04596	-10.92
381.250	7.98	387.8	0.04085	0.04595	-11.11
381.446	7.98	386.2	0.04088	0.04580	-10.74
381.458	7.98	386.2	0.04069	0.04580	-11.15
381.693	7.98	384.3	0.04060	0.04561	-10.99
381.690	7.98	384.4	0.04053	0.04562	-11.16
381.937	7.98	382.4	0.04063	0.04542	-10.55
381.940	7.98	382.4	0.04056	0.04542	-10.71
382.216	7.98	380.1	0.04061	0.04520	-10.15
382.233	7.98	379.9	0.04059	0.04518	-10.16
381.188	7.47	337.7	0.03770	0.04174	-9.68
381.192	7.47	337.7	0.03777	0.04174	-9.51
381.324	7.47	336.9	0.03726	0.04165	-10.55

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
381.325	7.47	336.9	0.03714	0.04165	-10.84
381.459	7.47	336.0	0.03777	0.04157	-9.13
381.468	7.47	336.0	0.03740	0.04156	-10.01
381.606	7.48	335.1	0.03731	0.04147	-10.03
381.604	7.48	335.1	0.03733	0.04147	-9.99
381.758	7.48	334.1	0.03722	0.04137	-10.03
381.762	7.47	334.1	0.03716	0.04136	-10.15
381.283	6.98	292.5	0.03421	0.03767	-9.18
381.302	6.98	292.4	0.03422	0.03766	-9.14
381.441	6.98	291.8	0.03477	0.03759	-7.51
381.439	6.98	291.8	0.03460	0.03760	-7.97
381.584	6.98	291.1	0.03437	0.03752	-8.41
381.597	6.98	291.1	0.03430	0.03752	-8.58
381.757	6.98	290.3	0.03424	0.03744	-8.54
381.757	6.98	290.3	0.03417	0.03744	-8.73
381.931	6.98	289.5	0.03427	0.03735	-8.25
381.937	6.98	289.5	0.03425	0.03735	-8.30
381.456	6.32	241.5	0.03088	0.03303	-6.52
381.635	6.32	240.9	0.03110	0.03298	-5.70
381.813	6.32	240.4	0.03069	0.03293	-6.80
381.996	6.32	239.8	0.03080	0.03288	-6.32
382.183	6.32	239.3	0.03093	0.03282	-5.77
381.626	5.56	193.1	0.02810	0.02892	-2.83
381.815	5.56	192.8	0.02816	0.02890	-2.55
382.037	5.56	192.4	0.02778	0.02887	-3.78
382.253	5.56	192.0	0.02786	0.02884	-3.40
382.513	5.56	191.3	0.02781	0.02879	-3.42
381.888	4.56	142.6	0.02501	0.02526	-0.98
382.127	4.56	142.4	0.02501	0.02525	-0.96
382.371	4.56	142.0	0.02522	0.02524	-0.09
382.626	4.55	141.6	0.02510	0.02523	-0.53
382.912	4.55	141.3	0.02496	0.02523	-1.07
331.276	22.24	1070.7	0.08902	0.09941	-10.45
331.486	22.25	1070.1	0.08858	0.09933	-10.82
331.704	22.24	1069.3	0.08772	0.09923	-11.60
331.946	22.22	1068.3	0.08837	0.09911	-10.83
332.199	22.21	1067.4	0.08790	0.09899	-11.21
331.295	20.30	1059.1	0.08683	0.09762	-11.05
331.498	20.32	1058.4	0.08710	0.09754	-10.71
331.717	20.32	1057.7	0.08650	0.09745	-11.24
331.960	20.30	1056.7	0.08644	0.09732	-11.18
332.215	20.29	1055.7	0.08645	0.09720	-11.06
331.287	16.18	1030.9	0.08336	0.09354	-10.89
331.501	16.18	1030.0	0.08345	0.09344	-10.69
331.744	16.20	1029.2	0.08273	0.09335	-11.38
331.992	16.21	1028.3	0.08271	0.09325	-11.30
332.254	16.21	1027.2	0.08271	0.09313	-11.19

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
331.308	12.66	1001.0	0.07949	0.08963	-11.31
331.542	12.65	999.8	0.07968	0.08950	-10.97
331.766	12.65	998.8	0.07858	0.08939	-12.09
332.028	12.66	997.7	0.07957	0.08928	-10.87
332.301	12.67	996.6	0.07912	0.08916	-11.26
331.036	9.74	971.1	0.07676	0.08610	-10.85
331.242	9.73	969.9	0.07682	0.08598	-10.66
331.474	9.73	968.7	0.07636	0.08586	-11.06
331.720	9.74	967.4	0.07618	0.08574	-11.15
331.965	9.75	966.3	0.07617	0.08563	-11.04
331.055	7.31	936.7	0.07319	0.08256	-11.35
331.280	7.31	935.3	0.07332	0.08244	-11.06
331.503	7.31	933.9	0.07324	0.08231	-11.02
331.748	7.30	932.2	0.07268	0.08216	-11.53
332.032	7.30	930.3	0.07273	0.08199	-11.29
330.936	5.64	905.3	0.07044	0.07978	-11.71
330.945	5.64	905.2	0.07073	0.07978	-11.34
331.088	5.64	904.1	0.07060	0.07969	-11.40
331.087	5.64	904.1	0.07017	0.07969	-11.94
331.250	5.64	902.8	0.06994	0.07959	-12.12
331.256	5.64	902.9	0.07000	0.07959	-12.05
331.403	5.65	901.8	0.07064	0.07951	-11.15
331.397	5.65	901.9	0.07049	0.07952	-11.35
331.576	5.65	900.5	0.07028	0.07941	-11.49
331.562	5.66	900.7	0.07086	0.07942	-10.78
330.827	4.38	871.3	0.06715	0.07731	-13.14
330.847	4.38	871.1	0.06683	0.07730	-13.54
330.963	4.38	869.9	0.06823	0.07722	-11.64
330.974	4.38	869.8	0.06784	0.07722	-12.14
331.109	4.39	868.5	0.06777	0.07713	-12.14
331.109	4.39	868.6	0.06753	0.07714	-12.45
331.257	4.39	867.1	0.06773	0.07703	-12.08
331.262	4.39	867.1	0.06764	0.07703	-12.19
331.419	4.39	865.4	0.06831	0.07692	-11.20
331.430	4.39	865.3	0.06785	0.07692	-11.79
330.836	3.73	844.3	0.06515	0.07582	-14.07
330.847	3.73	844.2	0.06504	0.07581	-14.21
330.978	3.73	842.3	0.06600	0.07571	-12.83
330.962	3.73	842.5	0.06643	0.07572	-12.27
331.110	3.73	840.3	0.06634	0.07561	-12.26
331.109	3.73	840.3	0.06672	0.07561	-11.76
331.265	3.73	838.1	0.06625	0.07550	-12.25
331.277	3.73	837.9	0.06616	0.07549	-12.36
331.434	3.73	835.7	0.06647	0.07538	-11.82
331.444	3.73	835.7	0.06650	0.07538	-11.78

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
401.352	25.08	844.2	0.07125	0.07637	-6.71
401.586	25.09	843.5	0.07052	0.07631	-7.59
401.840	25.10	842.6	0.07074	0.07623	-7.20
402.114	25.09	841.6	0.07057	0.07614	-7.32
402.413	25.08	840.3	0.07051	0.07603	-7.26
401.338	21.50	797.4	0.06662	0.07190	-7.34
401.587	21.50	796.5	0.06656	0.07182	-7.32
401.870	21.51	795.4	0.06628	0.07173	-7.59
402.164	21.50	794.1	0.06597	0.07162	-7.89
402.482	21.49	792.7	0.06637	0.07150	-7.17
401.393	18.47	744.7	0.06213	0.06745	-7.89
401.652	18.47	743.5	0.06251	0.06736	-7.20
401.927	18.46	742.0	0.06249	0.06724	-7.07
402.242	18.46	740.5	0.06202	0.06712	-7.60
402.592	18.46	738.9	0.06216	0.06700	-7.22
401.244	16.30	695.5	0.05906	0.06376	-7.38
401.260	16.30	695.3	0.05910	0.06375	-7.29
401.437	16.30	694.3	0.05880	0.06368	-7.66
401.440	16.29	694.3	0.05938	0.06367	-6.74
401.642	16.29	693.2	0.05880	0.06359	-7.53
401.634	16.29	693.2	0.05871	0.06360	-7.68
401.845	16.30	692.2	0.05880	0.06352	-7.42
401.848	16.30	692.2	0.05886	0.06352	-7.34
402.058	16.30	691.1	0.05875	0.06344	-7.39
402.054	16.30	691.2	0.05869	0.06344	-7.49
401.285	14.48	640.2	0.05587	0.06001	-6.89
401.298	14.48	640.1	0.05567	0.06000	-7.21
401.493	14.48	638.9	0.05580	0.05991	-6.86
401.488	14.48	638.9	0.05582	0.05991	-6.83
401.699	14.48	637.6	0.05526	0.05982	-7.62
401.709	14.48	637.5	0.05532	0.05982	-7.52
401.913	14.48	636.3	0.05526	0.05973	-7.48
401.908	14.48	636.5	0.05515	0.05974	-7.68
402.133	14.48	635.2	0.05519	0.05965	-7.47
402.130	14.48	635.2	0.05524	0.05965	-7.39
401.353	13.30	594.7	0.05310	0.05712	-7.04
401.350	13.30	594.7	0.05262	0.05712	-7.88
401.537	13.30	593.4	0.05259	0.05703	-7.79
401.533	13.30	593.4	0.05262	0.05704	-7.74
401.740	13.30	592.1	0.05259	0.05694	-7.64
401.751	13.30	592.1	0.05253	0.05694	-7.74
401.983	13.30	590.7	0.05256	0.05684	-7.53
401.977	13.31	590.8	0.05269	0.05684	-7.31
402.220	13.31	589.2	0.05248	0.05674	-7.50
402.224	13.31	589.2	0.05240	0.05674	-7.64
401.208	12.16	542.4	0.05011	0.05394	-7.11
401.205	12.16	542.5	0.05015	0.05395	-7.04
401.398	12.17	541.3	0.04993	0.05386	-7.29

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
401.388	12.17	541.3	0.05008	0.05386	-7.02
401.592	12.16	539.8	0.04937	0.05376	-8.16
401.615	12.16	539.6	0.04967	0.05374	-7.58
401.842	12.16	538.1	0.04960	0.05363	-7.52
401.836	12.16	538.1	0.04968	0.05363	-7.37
402.079	12.16	536.5	0.04986	0.05352	-6.83
402.089	12.16	536.5	0.04974	0.05352	-7.05
401.311	11.20	488.5	0.04685	0.05062	-7.45
401.331	11.20	488.4	0.04671	0.05061	-7.71
401.513	11.20	487.3	0.04699	0.05053	-7.00
401.511	11.20	487.2	0.04694	0.05052	-7.09
401.739	11.20	485.6	0.04639	0.05040	-7.96
401.746	11.20	485.5	0.04665	0.05040	-7.43
401.981	11.20	483.9	0.04659	0.05028	-7.34
401.989	11.20	483.9	0.04666	0.05027	-7.18
402.250	11.20	482.2	0.04654	0.05014	-7.19
402.239	11.20	482.3	0.04687	0.05016	-6.55
401.383	10.44	441.0	0.04416	0.04756	-7.14
401.400	10.44	441.0	0.04451	0.04755	-6.40
401.605	10.44	439.8	0.04448	0.04746	-6.28
401.604	10.45	439.9	0.04430	0.04746	-6.67
401.810	10.45	438.7	0.04414	0.04737	-6.81
401.819	10.45	438.7	0.04396	0.04736	-7.19
402.075	10.45	437.1	0.04413	0.04724	-6.58
402.068	10.45	437.2	0.04417	0.04724	-6.50
402.354	10.45	435.3	0.04391	0.04710	-6.76
402.358	10.44	435.2	0.04386	0.04709	-6.86
401.459	9.72	393.4	0.04164	0.04428	-5.97
401.464	9.72	393.3	0.04180	0.04427	-5.59
401.698	9.71	391.9	0.04140	0.04416	-6.25
401.696	9.71	391.9	0.04157	0.04416	-5.86
401.937	9.71	390.5	0.04118	0.04405	-6.51
401.943	9.71	390.5	0.04111	0.04404	-6.66
402.210	9.71	389.2	0.04130	0.04393	-5.99
402.208	9.72	389.3	0.04118	0.04394	-6.28
402.512	9.72	387.7	0.04109	0.04381	-6.20
402.508	9.72	387.8	0.04091	0.04381	-6.62
401.331	8.93	343.0	0.03832	0.04061	-5.64
401.338	8.93	342.9	0.03843	0.04060	-5.35
401.554	8.93	341.9	0.03842	0.04052	-5.18
401.560	8.93	341.9	0.03825	0.04051	-5.58
401.836	8.93	340.7	0.03836	0.04041	-5.07
401.836	8.94	340.8	0.03799	0.04042	-6.01
402.109	8.94	339.7	0.03824	0.04032	-5.16
402.109	8.94	339.8	0.03795	0.04032	-5.89
402.416	8.94	338.5	0.03808	0.04022	-5.31
402.410	8.94	338.5	0.03801	0.04022	-5.49
401.441	8.13	292.9	0.03510	0.03679	-4.60

Table 9. Thermal conductivity for R410A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
401.452	8.13	292.9	0.03523	0.03679	-4.23
401.698	8.13	292.0	0.03513	0.03671	-4.32
401.697	8.14	292.1	0.03518	0.03672	-4.20
401.983	8.14	291.3	0.03483	0.03665	-4.97
401.995	8.14	291.3	0.03487	0.03665	-4.86
402.302	8.14	290.3	0.03463	0.03657	-5.31
402.310	8.14	290.3	0.03473	0.03657	-5.04
402.648	8.14	289.2	0.03484	0.03648	-4.49
402.668	8.14	289.0	0.03482	0.03646	-4.51
401.597	7.24	242.3	0.03243	0.03295	-1.58
401.598	7.24	242.3	0.03246	0.03295	-1.49
401.887	7.24	241.7	0.03235	0.03291	-1.70
401.873	7.24	241.8	0.03255	0.03292	-1.12
402.189	7.24	241.2	0.03213	0.03287	-2.26
402.194	7.24	241.2	0.03195	0.03287	-2.81
402.554	7.25	240.4	0.03202	0.03282	-2.44
402.543	7.24	240.4	0.03199	0.03282	-2.52
402.951	7.24	239.3	0.03214	0.03274	-1.85
402.953	7.24	239.3	0.03201	0.03274	-2.23
401.794	6.17	189.9	0.02941	0.02927	0.47
401.798	6.17	190.0	0.02933	0.02928	0.18
402.129	6.17	189.5	0.02921	0.02926	-0.17
402.132	6.17	189.6	0.02922	0.02926	-0.15
402.485	6.17	189.1	0.02919	0.02924	-0.19
402.484	6.17	189.0	0.02931	0.02924	0.23
402.908	6.17	188.3	0.02924	0.02921	0.10
402.917	6.17	188.2	0.02916	0.02921	-0.16
403.337	6.17	187.6	0.02913	0.02918	-0.18
403.366	6.17	187.5	0.02918	0.02918	0.00
401.666	4.99	141.6	0.02679	0.02637	1.60
401.671	4.99	141.6	0.02698	0.02637	2.31
401.885	4.99	141.5	0.02668	0.02638	1.15
401.874	4.99	141.4	0.02677	0.02637	1.51
402.096	4.99	141.1	0.02656	0.02637	0.72
402.098	4.98	141.0	0.02668	0.02637	1.19
402.332	4.98	140.8	0.02658	0.02637	0.80
402.332	4.98	140.7	0.02674	0.02637	1.41
402.581	4.98	140.6	0.02679	0.02637	1.57
402.583	4.99	140.7	0.02679	0.02638	1.55

Table 10. Thermal conductivity for R507A measured by the steady-state technique; data are listed in the order of measurement.

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
362.556	0.641	22.23	0.02048	0.02314	-11.49
362.845	0.642	22.21	0.02056	0.02317	-11.26
363.135	0.642	22.20	0.02061	0.02320	-11.16
363.441	0.641	22.16	0.02069	0.02323	-10.94
363.782	0.641	22.11	0.02081	0.02327	-10.56
362.627	0.299	10.05	0.02022	0.02313	-12.58
362.914	0.299	10.03	0.02019	0.02316	-12.82
363.241	0.299	10.04	0.02016	0.02319	-13.08
363.592	0.300	10.05	0.02016	0.02323	-13.22
363.941	0.300	10.05	0.02016	0.02327	-13.35
362.494	0.208	6.95	0.02010	0.02311	-13.04
362.714	0.209	6.96	0.02007	0.02314	-13.25
362.928	0.209	6.96	0.02008	0.02316	-13.29
363.167	0.209	6.95	0.02007	0.02318	-13.43
363.421	0.208	6.93	0.02010	0.02321	-13.40
362.502	0.109	3.61	0.01990	0.02311	-13.90
362.719	0.109	3.61	0.01985	0.02314	-14.20
362.947	0.109	3.61	0.01986	0.02316	-14.25
363.191	0.109	3.60	0.01987	0.02318	-14.30
363.439	0.108	3.58	0.01989	0.02321	-14.31
382.073	0.626	20.37	0.02258	0.02519	-10.37
382.279	0.627	20.37	0.02257	0.02522	-10.49
382.523	0.627	20.37	0.02262	0.02524	-10.38
382.778	0.627	20.35	0.02264	0.02527	-10.40
381.739	0.360	11.49	0.02247	0.02515	-10.65
381.944	0.360	11.50	0.02238	0.02517	-11.08
382.177	0.361	11.50	0.02232	0.02519	-11.41
382.393	0.361	11.50	0.02234	0.02522	-11.41
382.672	0.361	11.49	0.02235	0.02525	-11.47
381.756	0.211	6.65	0.02225	0.02515	-11.52
381.944	0.211	6.66	0.02222	0.02517	-11.71
382.669	0.210	6.61	0.02219	0.02524	-12.10
381.762	0.107	3.36	0.02207	0.02515	-12.23
381.967	0.107	3.35	0.02202	0.02517	-12.51
382.203	0.107	3.36	0.02196	0.02519	-12.83
382.416	0.107	3.36	0.02198	0.02522	-12.83
382.689	0.108	3.37	0.02195	0.02524	-13.05
401.816	0.471	14.31	0.02485	0.02732	-9.03
401.513	0.473	14.41	0.02442	0.02729	-10.50
401.721	0.473	14.39	0.02436	0.02731	-10.79
401.921	0.473	14.39	0.02435	0.02733	-10.90
402.169	0.474	14.40	0.02443	0.02736	-10.70
402.388	0.473	14.37	0.02441	0.02738	-10.85
401.717	0.317	9.55	0.02460	0.02730	-9.90
401.904	0.317	9.54	0.02456	0.02732	-10.12

Table 10. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
402.161	0.316	9.52	0.02453	0.02735	-10.32
402.386	0.316	9.52	0.02452	0.02738	-10.44
401.506	0.215	6.43	0.02456	0.02728	-9.97
401.722	0.214	6.41	0.02448	0.02730	-10.34
401.952	0.214	6.40	0.02441	0.02733	-10.68
402.141	0.214	6.41	0.02443	0.02735	-10.67
402.407	0.215	6.42	0.02445	0.02738	-10.70
401.523	0.109	3.24	0.02425	0.02728	-11.11
401.936	0.109	3.24	0.02415	0.02733	-11.62
402.171	0.109	3.25	0.02414	0.02735	-11.74
402.424	0.109	3.23	0.02413	0.02738	-11.87
300.010	0.294	12.26	0.01431	0.01688	-15.24
300.258	0.286	11.89	0.01429	0.01691	-15.47
300.526	0.279	11.55	0.01432	0.01693	-15.42
300.816	0.271	11.22	0.01433	0.01696	-15.49
301.127	0.263	10.86	0.01434	0.01699	-15.58
299.819	0.108	4.34	0.01406	0.01685	-16.57
300.326	0.107	4.33	0.01403	0.01690	-16.98
300.613	0.107	4.30	0.01404	0.01693	-17.06
300.921	0.106	4.25	0.01405	0.01696	-17.14
315.132	0.303	11.94	0.01565	0.01834	-14.66
315.354	0.303	11.90	0.01562	0.01836	-14.92
315.583	0.301	11.83	0.01563	0.01838	-14.97
316.134	0.300	11.77	0.01569	0.01844	-14.89
315.152	0.209	8.10	0.01562	0.01833	-14.80
315.355	0.208	8.06	0.01557	0.01835	-15.17
315.878	0.208	8.04	0.01555	0.01840	-15.51
316.160	0.208	8.03	0.01555	0.01843	-15.64
314.911	0.108	4.13	0.01553	0.01831	-15.17
315.648	0.108	4.12	0.01544	0.01838	-15.99
315.905	0.108	4.12	0.01544	0.01840	-16.10
330.582	0.306	11.41	0.01712	0.01986	-13.80
330.808	0.306	11.41	0.01711	0.01988	-13.95
331.068	0.305	11.37	0.01710	0.01991	-14.11
330.371	0.206	7.58	0.01708	0.01983	-13.89
330.578	0.205	7.55	0.01703	0.01986	-14.23
330.846	0.205	7.53	0.01701	0.01988	-14.45
331.083	0.205	7.54	0.01702	0.01991	-14.50
330.181	0.107	3.90	0.01695	0.01981	-14.45
330.863	0.107	3.88	0.01685	0.01988	-15.25
331.119	0.107	3.90	0.01687	0.01991	-15.26

Table 11. Thermal conductivity for R507A measured by the transient hot-wire technique; data are listed in the order of measurement.

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
301.498	32.50	1212.4	0.07949	0.08290	-4.11
301.673	32.48	1211.9	0.07916	0.08285	-4.45
301.869	32.47	1211.4	0.07906	0.08279	-4.50
302.065	32.46	1210.9	0.07933	0.08273	-4.11
302.281	32.46	1210.4	0.07911	0.08268	-4.31
301.517	25.47	1187.4	0.07549	0.07917	-4.65
301.727	25.47	1186.8	0.07581	0.07912	-4.18
301.926	25.46	1186.3	0.07577	0.07906	-4.16
302.132	25.47	1185.8	0.07559	0.07901	-4.33
302.364	25.48	1185.2	0.07566	0.07895	-4.17
301.587	17.86	1154.6	0.07140	0.07458	-4.26
301.789	17.86	1154.0	0.07171	0.07453	-3.78
302.019	17.86	1153.3	0.07190	0.07446	-3.44
302.232	17.86	1152.7	0.07145	0.07441	-3.97
302.460	17.87	1152.0	0.07154	0.07435	-3.77
301.636	12.22	1124.2	0.06919	0.07117	-2.79
301.873	12.21	1123.4	0.06906	0.07110	-2.87
302.092	12.21	1122.6	0.06919	0.07104	-2.60
302.331	12.22	1121.9	0.06846	0.07097	-3.53
302.564	12.22	1121.1	0.06941	0.07090	-2.10
301.297	12.24	1125.5	0.06924	0.07128	-2.87
301.305	12.24	1125.4	0.06900	0.07128	-3.20
301.495	12.24	1124.8	0.06922	0.07123	-2.82
301.494	12.24	1124.8	0.07000	0.07123	-1.72
301.695	12.24	1124.1	0.06980	0.07117	-1.92
301.699	12.23	1124.1	0.06941	0.07116	-2.46
301.916	12.23	1123.4	0.06867	0.07110	-3.42
301.904	12.23	1123.4	0.07097	0.07110	-0.19
302.121	12.23	1122.6	0.07019	0.07104	-1.19
302.128	12.23	1122.6	0.06906	0.07104	-2.78
301.339	7.95	1096.8	0.06879	0.06834	0.66
301.348	7.95	1096.7	0.06841	0.06834	0.10
301.541	7.95	1096.0	0.06849	0.06828	0.31
301.549	7.95	1095.9	0.06782	0.06827	-0.67
301.756	7.95	1095.1	0.06815	0.06821	-0.09
301.751	7.96	1095.2	0.06881	0.06821	0.88
301.967	7.96	1094.4	0.06798	0.06814	-0.24
301.969	7.96	1094.4	0.06858	0.06814	0.64
302.201	7.96	1093.5	0.06792	0.06807	-0.22
302.195	7.96	1093.5	0.06930	0.06807	1.80
301.025	4.25	1066.4	0.06567	0.06550	0.26
301.028	4.25	1066.4	0.06738	0.06550	2.87
301.210	4.25	1065.6	0.06597	0.06544	0.81
301.203	4.25	1065.6	0.06660	0.06544	1.78
301.399	4.25	1064.7	0.06727	0.06537	2.91
301.414	4.25	1064.7	0.06530	0.06537	-0.10
301.601	4.25	1063.8	0.06742	0.06530	3.25

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
301.818	4.25	1062.8	0.06784	0.06522	4.01
301.829	4.25	1062.8	0.06659	0.06522	2.10
301.056	1.54	1035.4	0.06581	0.06292	4.60
301.257	1.54	1034.3	0.06475	0.06284	3.05
301.433	1.53	1033.3	0.06627	0.06276	5.59
301.652	1.54	1032.1	0.06616	0.06268	5.56
301.860	1.53	1030.9	0.06555	0.06259	4.73
361.909	26.29	1028.3	0.06562	0.06661	-1.48
362.117	26.30	1027.8	0.06511	0.06658	-2.20
362.345	26.30	1027.2	0.06532	0.06654	-1.84
362.574	26.29	1026.5	0.06556	0.06650	-1.42
362.821	26.28	1025.7	0.06537	0.06646	-1.63
361.946	21.67	994.3	0.06200	0.06376	-2.76
362.165	21.68	993.7	0.06214	0.06373	-2.49
362.401	21.68	993.0	0.06227	0.06369	-2.23
362.650	21.68	992.2	0.06198	0.06365	-2.62
362.903	21.66	991.3	0.06221	0.06360	-2.18
361.811	16.13	940.8	0.05768	0.05976	-3.48
362.027	16.14	940.1	0.05768	0.05972	-3.42
362.257	16.14	939.3	0.05788	0.05969	-3.03
362.509	16.14	938.3	0.05768	0.05964	-3.29
362.766	16.13	937.2	0.05759	0.05959	-3.35
361.855	12.63	892.3	0.05415	0.05665	-4.41
362.093	12.63	891.2	0.05411	0.05660	-4.41
362.348	12.64	890.2	0.05418	0.05656	-4.21
362.611	12.64	889.1	0.05424	0.05651	-4.02
362.895	12.65	887.8	0.05417	0.05646	-4.06
361.727	9.93	838.9	0.05097	0.05371	-5.11
361.955	9.92	837.5	0.05122	0.05366	-4.54
362.191	9.92	836.1	0.05063	0.05360	-5.55
362.452	9.93	834.7	0.05073	0.05355	-5.26
362.727	9.93	833.2	0.05080	0.05349	-5.03
361.784	8.21	787.2	0.04848	0.05135	-5.59
362.023	8.21	785.4	0.04838	0.05129	-5.67
362.275	8.21	783.5	0.04824	0.05123	-5.83
362.538	8.21	781.7	0.04833	0.05116	-5.54
362.822	8.22	779.6	0.04815	0.05110	-5.77
361.816	7.03	732.6	0.04610	0.04938	-6.64
362.064	7.03	730.2	0.04627	0.04931	-6.16
362.334	7.02	727.5	0.04593	0.04923	-6.70
362.620	7.02	724.6	0.04583	0.04915	-6.75
362.899	7.03	721.9	0.04587	0.04907	-6.53
361.625	6.29	681.7	0.04436	0.04806	-7.69
361.853	6.28	678.6	0.04458	0.04799	-7.10
362.109	6.28	675.2	0.04410	0.04791	-7.96
362.391	6.29	671.6	0.04416	0.04783	-7.68
362.673	6.29	668.0	0.04404	0.04776	-7.78

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
361.448	5.80	630.0	0.04286	0.04724	-9.27
361.653	5.80	626.6	0.04284	0.04718	-9.20
361.882	5.80	622.7	0.04303	0.04711	-8.66
362.122	5.80	618.5	0.04265	0.04704	-9.33
362.392	5.80	613.8	0.04276	0.04695	-8.93
361.427	5.44	567.4	0.04190	0.04659	-10.07
361.429	5.44	567.4	0.04187	0.04659	-10.13
361.646	5.44	562.5	0.04163	0.04650	-10.47
361.654	5.44	562.4	0.04161	0.04649	-10.51
361.883	5.44	557.3	0.04145	0.04639	-10.65
361.890	5.44	557.2	0.04164	0.04639	-10.24
362.140	5.44	551.6	0.04118	0.04627	-11.01
362.138	5.44	551.7	0.04126	0.04627	-10.84
362.402	5.44	545.9	0.04112	0.04614	-10.89
362.396	5.44	546.0	0.04120	0.04615	-10.72
361.312	5.24	518.7	0.04083	0.04592	-11.09
361.321	5.24	518.6	0.04088	0.04592	-10.97
361.515	5.24	513.8	0.04061	0.04578	-11.29
361.520	5.24	513.7	0.04044	0.04578	-11.66
361.733	5.24	508.5	0.04023	0.04562	-11.81
361.715	5.24	508.9	0.04036	0.04563	-11.56
361.957	5.24	503.0	0.04010	0.04545	-11.76
361.961	5.24	502.8	0.04013	0.04544	-11.69
362.193	5.24	497.2	0.03978	0.04526	-12.10
362.218	5.24	496.6	0.03969	0.04524	-12.26
361.326	5.06	465.0	0.03899	0.04453	-12.44
361.337	5.06	464.6	0.03935	0.04451	-11.60
361.528	5.06	460.0	0.03869	0.04431	-12.68
361.538	5.06	459.8	0.03875	0.04430	-12.52
361.766	5.06	454.5	0.03843	0.04405	-12.77
361.762	5.06	454.7	0.03844	0.04406	-12.76
362.004	5.06	449.2	0.03808	0.04380	-13.06
362.011	5.06	449.1	0.03821	0.04380	-12.76
362.265	5.06	443.6	0.03766	0.04352	-13.47
362.266	5.06	443.5	0.03776	0.04352	-13.24
361.390	4.91	416.8	0.03724	0.04255	-12.49
361.391	4.91	416.7	0.03721	0.04255	-12.55
361.610	4.91	412.4	0.03676	0.04229	-13.08
361.605	4.91	412.4	0.03670	0.04230	-13.23
361.834	4.91	407.9	0.03654	0.04203	-13.06
361.840	4.91	407.8	0.03633	0.04202	-13.54
362.100	4.91	403.0	0.03591	0.04172	-13.93
362.100	4.91	402.9	0.03598	0.04172	-13.76
362.377	4.91	397.9	0.03558	0.04141	-14.08
362.390	4.91	397.8	0.03556	0.04140	-14.11
361.508	4.76	370.4	0.03454	0.04006	-13.77
361.514	4.76	370.4	0.03452	0.04005	-13.81
361.728	4.76	367.1	0.03431	0.03982	-13.85

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
361.745	4.76	366.9	0.03432	0.03981	-13.79
361.999	4.76	363.1	0.03403	0.03955	-13.95
362.009	4.75	363.0	0.03400	0.03953	-14.00
362.297	4.75	358.9	0.03358	0.03925	-14.44
362.297	4.75	358.9	0.03351	0.03925	-14.62
362.599	4.75	354.8	0.03324	0.03896	-14.69
362.621	4.75	354.6	0.03321	0.03894	-14.73
361.649	4.58	327.2	0.03182	0.03736	-14.83
361.666	4.58	327.0	0.03208	0.03734	-14.10
361.923	4.58	324.3	0.03185	0.03714	-14.25
361.931	4.58	324.3	0.03184	0.03714	-14.27
362.231	4.58	321.3	0.03171	0.03692	-14.10
362.238	4.58	321.2	0.03159	0.03691	-14.42
362.563	4.58	318.0	0.03124	0.03668	-14.83
362.563	4.58	318.1	0.03121	0.03668	-14.92
362.907	4.58	314.8	0.03107	0.03645	-14.75
362.920	4.58	314.8	0.03110	0.03644	-14.66
361.877	4.36	283.7	0.02932	0.03449	-14.99
361.881	4.36	283.7	0.02940	0.03449	-14.75
362.185	4.36	281.5	0.02938	0.03433	-14.42
362.199	4.36	281.5	0.02942	0.03433	-14.30
362.534	4.36	279.3	0.02918	0.03417	-14.61
362.532	4.37	279.3	0.02914	0.03417	-14.73
362.909	4.37	276.9	0.02901	0.03400	-14.69
362.914	4.37	276.9	0.02906	0.03400	-14.54
363.306	4.37	274.5	0.02885	0.03384	-14.74
363.309	4.37	274.5	0.02885	0.03384	-14.73
361.844	4.02	234.4	0.02675	0.03131	-14.56
361.852	4.02	234.4	0.02670	0.03131	-14.72
362.188	4.02	233.0	0.02681	0.03123	-14.15
362.190	4.03	233.0	0.02684	0.03123	-14.06
362.558	4.03	231.6	0.02674	0.03115	-14.15
362.556	4.03	231.6	0.02671	0.03115	-14.25
362.956	4.03	230.1	0.02674	0.03106	-13.91
362.969	4.03	230.0	0.02666	0.03106	-14.16
363.408	4.03	228.3	0.02654	0.03096	-14.29
363.405	4.03	228.3	0.02652	0.03096	-14.35
362.095	3.62	189.3	0.02461	0.02868	-14.19
362.095	3.62	189.4	0.02458	0.02868	-14.30
362.487	3.62	188.5	0.02458	0.02865	-14.22
362.489	3.62	188.5	0.02458	0.02865	-14.22
362.913	3.62	187.5	0.02458	0.02863	-14.13
362.926	3.62	187.5	0.02454	0.02863	-14.27
363.388	3.62	186.5	0.02455	0.02860	-14.15
363.372	3.62	186.5	0.02460	0.02860	-13.98
363.878	3.62	185.3	0.02454	0.02856	-14.09
363.882	3.62	185.3	0.02461	0.02856	-13.84
362.400	3.03	140.4	0.02278	0.02632	-13.46

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
362.414	3.03	140.4	0.02275	0.02632	-13.58
362.850	3.03	139.9	0.02274	0.02634	-13.66
362.863	3.03	139.9	0.02280	0.02634	-13.44
363.344	3.02	139.3	0.02279	0.02635	-13.52
363.360	3.02	139.2	0.02274	0.02635	-13.71
363.891	3.02	138.6	0.02277	0.02637	-13.65
363.893	3.02	138.5	0.02279	0.02637	-13.57
364.465	3.02	137.9	0.02277	0.02639	-13.72
364.476	3.02	137.9	0.02279	0.02639	-13.64
362.469	3.02	140.1	0.02278	0.02631	-13.43
362.470	3.02	140.1	0.02269	0.02631	-13.77
362.924	3.02	139.5	0.02272	0.02633	-13.70
362.920	3.02	139.5	0.02271	0.02633	-13.74
363.421	3.02	139.0	0.02277	0.02635	-13.58
363.413	3.02	139.0	0.02277	0.02635	-13.58
363.943	3.02	138.5	0.02276	0.02637	-13.69
363.943	3.02	138.5	0.02277	0.02637	-13.65
364.524	3.02	137.9	0.02281	0.02639	-13.58
364.518	3.02	137.9	0.02278	0.02639	-13.69
362.782	2.22	91.4	0.02111	0.02457	-14.09
362.799	2.22	91.4	0.02117	0.02457	-13.85
363.319	2.22	91.1	0.02120	0.02462	-13.89
363.319	2.23	91.2	0.02118	0.02462	-13.97
363.886	2.23	90.9	0.02124	0.02436	-12.80
363.895	2.23	90.9	0.02125	0.02436	-12.77
364.514	2.23	90.6	0.02128	0.02441	-12.84
364.518	2.23	90.5	0.02130	0.02441	-12.75
365.186	2.22	90.1	0.02129	0.02447	-13.00
365.183	2.22	90.0	0.02129	0.02447	-12.99
362.216	1.17	42.7	0.02002	0.02323	-13.80
362.715	1.15	41.9	0.02002	0.02327	-13.96
363.267	1.16	42.0	0.02018	0.02333	-13.49
363.895	1.16	42.2	0.02020	0.02340	-13.66
364.549	1.17	42.4	0.02023	0.02347	-13.79
362.398	0.64	22.1	0.01973	0.02312	-14.67
362.850	0.64	22.1	0.01978	0.02317	-14.63
363.332	0.64	22.1	0.01992	0.02322	-14.21
363.859	0.64	22.0	0.01993	0.02328	-14.37
364.419	0.64	21.9	0.01996	0.02333	-14.46
362.624	0.30	10.0	0.01982	0.02313	-14.31
363.110	0.30	9.9	0.01987	0.02318	-14.28
363.645	0.30	9.9	0.01990	0.02324	-14.35
364.225	0.30	9.9	0.01993	0.02330	-14.45
364.837	0.30	9.9	0.01997	0.02336	-14.51
362.494	0.20	6.8	0.01982	0.02311	-14.25
362.854	0.20	6.8	0.01983	0.02315	-14.34
363.240	0.21	6.8	0.01991	0.02319	-14.15
363.651	0.21	6.8	0.01989	0.02323	-14.39

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
364.086	0.21	6.8	0.01993	0.02328	-14.39
362.652	0.11	3.5	0.01993	0.02313	-13.83
363.035	0.11	3.5	0.01991	0.02317	-14.06
363.447	0.11	3.5	0.01994	0.02321	-14.09
363.881	0.11	3.5	0.01994	0.02326	-14.26
364.341	0.11	3.5	0.02001	0.02330	-14.14
316.819	37.77	1193.8	0.07957	0.08178	-2.70
317.015	37.79	1193.4	0.07963	0.08175	-2.59
317.214	37.80	1193.0	0.07955	0.08171	-2.64
317.429	37.81	1192.6	0.07945	0.08166	-2.71
317.633	37.81	1192.1	0.07946	0.08161	-2.64
316.868	28.56	1159.9	0.07498	0.07696	-2.57
317.079	28.56	1159.3	0.07499	0.07691	-2.50
317.284	28.58	1158.9	0.07491	0.07687	-2.55
317.511	28.59	1158.3	0.07477	0.07682	-2.67
317.743	28.59	1157.8	0.07482	0.07677	-2.54
316.736	21.86	1130.1	0.07099	0.07295	-2.68
316.947	21.87	1129.5	0.07107	0.07290	-2.51
317.138	21.87	1129.0	0.07118	0.07286	-2.30
317.387	21.85	1128.2	0.07103	0.07278	-2.41
317.614	21.84	1127.5	0.07087	0.07273	-2.55
316.804	16.55	1100.7	0.06749	0.06978	-3.28
317.023	16.56	1100.1	0.06754	0.06973	-3.14
317.247	16.57	1099.4	0.06746	0.06968	-3.19
317.472	16.58	1098.7	0.06742	0.06963	-3.17
317.715	16.58	1098.0	0.06740	0.06957	-3.12
316.857	12.29	1071.7	0.06474	0.06693	-3.27
317.091	12.30	1070.8	0.06483	0.06687	-3.04
317.327	12.30	1070.0	0.06488	0.06680	-2.88
317.575	12.30	1069.1	0.06467	0.06674	-3.10
317.829	12.29	1068.1	0.06443	0.06666	-3.35
316.740	8.52	1039.7	0.06238	0.06406	-2.63
316.953	8.50	1038.6	0.06246	0.06399	-2.39
317.194	8.50	1037.6	0.06149	0.06391	-3.79
317.439	8.50	1036.5	0.06135	0.06384	-3.90
317.682	8.50	1035.5	0.06265	0.06377	-1.76
316.800	5.75	1008.3	0.05979	0.06154	-2.85
317.026	5.74	1007.1	0.06009	0.06147	-2.24
317.271	5.74	1005.9	0.05899	0.06138	-3.90
317.520	5.74	1004.6	0.05908	0.06130	-3.63
317.785	5.75	1003.4	0.05899	0.06123	-3.65
316.398	3.54	977.4	0.05886	0.05930	-0.75
316.630	3.54	976.0	0.05811	0.05921	-1.87
316.848	3.54	974.6	0.05809	0.05913	-1.76
317.106	3.54	973.0	0.05773	0.05904	-2.21
317.341	3.54	971.5	0.05741	0.05895	-2.61
316.102	2.19	951.7	0.05636	0.05765	-2.25

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
316.108	2.19	951.7	0.05734	0.05765	-0.54
316.298	2.19	950.3	0.05668	0.05758	-1.56
316.295	2.19	950.4	0.05627	0.05758	-2.27
316.494	2.19	948.9	0.05612	0.05750	-2.40
316.498	2.19	948.9	0.05610	0.05750	-2.43
316.706	2.19	947.3	0.05681	0.05741	-1.04
316.697	2.18	947.2	0.05725	0.05740	-0.27
316.936	2.18	945.4	0.05743	0.05730	0.22
316.941	2.18	945.3	0.05570	0.05730	-2.79
381.305	23.15	947.7	0.06202	0.06195	0.12
381.496	23.16	947.2	0.06205	0.06193	0.20
381.678	23.15	946.6	0.06212	0.06190	0.36
381.876	23.15	945.9	0.06178	0.06187	-0.15
382.085	23.15	945.4	0.06102	0.06185	-1.34
381.469	18.21	893.7	0.05657	0.05834	-3.03
381.650	18.22	893.2	0.05663	0.05832	-2.89
381.844	18.22	892.5	0.05630	0.05829	-3.42
382.050	18.22	891.8	0.05637	0.05826	-3.25
382.271	18.21	890.9	0.05647	0.05823	-3.02
381.624	14.70	840.1	0.05309	0.05525	-3.90
381.823	14.71	839.3	0.05311	0.05522	-3.82
382.035	14.71	838.4	0.05289	0.05519	-4.17
382.247	14.72	837.6	0.05310	0.05516	-3.74
382.458	14.72	836.7	0.05305	0.05513	-3.78
381.553	12.38	791.7	0.05014	0.05281	-5.06
381.750	12.38	790.7	0.05040	0.05278	-4.51
381.950	12.39	789.7	0.05040	0.05275	-4.45
382.149	12.39	788.8	0.04997	0.05272	-5.22
382.371	12.39	787.7	0.05012	0.05269	-4.87
381.650	10.58	738.6	0.04758	0.05051	-5.81
381.843	10.58	737.4	0.04777	0.05048	-5.37
382.044	10.58	736.2	0.04746	0.05044	-5.92
382.257	10.58	735.0	0.04744	0.05041	-5.89
382.482	10.59	733.7	0.04750	0.05037	-5.70
381.716	9.30	686.0	0.04551	0.04858	-6.32
381.920	9.31	684.6	0.04554	0.04854	-6.18
382.129	9.31	683.1	0.04540	0.04850	-6.40
382.345	9.31	681.6	0.04536	0.04846	-6.40
382.577	9.31	679.9	0.04537	0.04842	-6.30
381.633	8.40	635.5	0.04337	0.04700	-7.73
381.836	8.40	633.8	0.04357	0.04696	-7.22
382.055	8.40	632.0	0.04336	0.04692	-7.58
382.272	8.40	630.2	0.04321	0.04687	-7.81
382.511	8.40	628.2	0.04335	0.04682	-7.41
381.700	7.70	581.4	0.04172	0.04555	-8.40
381.904	7.70	579.6	0.04183	0.04550	-8.06
382.121	7.70	577.5	0.04174	0.04545	-8.15

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
382.357	7.71	575.4	0.04145	0.04539	-8.68
382.586	7.71	573.2	0.04156	0.04533	-8.33
381.591	7.19	532.3	0.03994	0.04427	-9.78
381.781	7.19	530.3	0.03982	0.04421	-9.93
382.002	7.19	527.9	0.03982	0.04414	-9.80
382.228	7.19	525.6	0.03988	0.04408	-9.52
382.454	7.19	523.3	0.03968	0.04401	-9.84
381.467	6.78	485.2	0.03837	0.04293	-10.61
381.665	6.78	483.1	0.03844	0.04286	-10.31
381.875	6.78	481.0	0.03836	0.04279	-10.35
382.085	6.78	478.9	0.03827	0.04271	-10.40
382.315	6.78	476.6	0.03793	0.04263	-11.03
381.525	6.78	484.7	0.03831	0.04291	-10.72
381.715	6.78	482.9	0.03839	0.04285	-10.40
381.901	6.78	481.0	0.03847	0.04279	-10.09
382.140	6.78	478.6	0.03824	0.04270	-10.45
382.369	6.78	476.2	0.03793	0.04262	-11.01
381.569	6.36	429.3	0.03647	0.04101	-11.08
381.789	6.36	427.4	0.03644	0.04093	-10.98
382.006	6.36	425.4	0.03624	0.04085	-11.29
382.237	6.36	423.3	0.03599	0.04077	-11.72
382.492	6.36	421.0	0.03586	0.04067	-11.83
381.462	6.01	383.5	0.03470	0.03916	-11.38
381.675	6.01	381.9	0.03452	0.03908	-11.68
381.890	6.01	380.3	0.03463	0.03901	-11.23
382.130	6.01	378.4	0.03433	0.03892	-11.80
382.381	6.01	376.4	0.03406	0.03884	-12.30
381.577	5.65	337.5	0.03249	0.03707	-12.34
381.796	5.65	336.3	0.03258	0.03701	-11.96
382.034	5.65	334.9	0.03254	0.03694	-11.92
382.294	5.65	333.5	0.03232	0.03688	-12.35
382.573	5.65	331.8	0.03202	0.03680	-12.99
381.711	5.24	290.3	0.03034	0.03477	-12.75
381.975	5.24	289.2	0.03037	0.03472	-12.54
382.227	5.25	288.1	0.03031	0.03468	-12.60
382.517	5.24	286.8	0.03017	0.03462	-12.86
382.832	5.24	285.4	0.03013	0.03456	-12.83
381.879	4.76	242.2	0.02837	0.03242	-12.49
382.157	4.76	241.4	0.02818	0.03239	-13.01
382.468	4.76	240.4	0.02815	0.03236	-13.02
382.794	4.76	239.4	0.02813	0.03233	-13.00
383.125	4.76	238.4	0.02810	0.03231	-13.02
382.105	4.15	192.3	0.02623	0.03013	-12.94
382.405	4.15	191.7	0.02621	0.03013	-13.01
382.751	4.15	191.1	0.02635	0.03013	-12.54
383.114	4.15	190.5	0.02619	0.03013	-13.08
383.501	4.15	189.9	0.02629	0.03014	-12.76
382.045	3.37	141.1	0.02429	0.02809	-13.54

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
382.389	3.37	140.8	0.02440	0.02811	-13.21
382.743	3.37	140.6	0.02440	0.02814	-13.29
383.133	3.37	140.2	0.02449	0.02816	-13.04
383.545	3.37	139.9	0.02449	0.02819	-13.13
382.308	2.45	93.1	0.02314	0.02636	-12.21
382.691	2.45	92.8	0.02306	0.02639	-12.62
383.093	2.45	92.5	0.02304	0.02643	-12.82
383.540	2.45	92.3	0.02308	0.02647	-12.81
384.004	2.45	92.1	0.02317	0.02652	-12.62
382.284	1.20	40.8	0.02196	0.02534	-13.32
382.583	1.20	40.9	0.02211	0.02537	-12.85
382.919	1.21	40.9	0.02210	0.02541	-13.02
383.278	1.21	41.0	0.02207	0.02545	-13.27
383.622	1.21	41.0	0.02219	0.02549	-12.93
382.322	1.15	38.8	0.02214	0.02532	-12.54
382.636	1.18	40.0	0.02212	0.02536	-12.78
382.963	1.19	40.4	0.02211	0.02540	-12.97
383.297	1.17	39.5	0.02207	0.02543	-13.21
383.670	1.15	38.8	0.02201	0.02546	-13.55
382.383	1.05	35.2	0.02198	0.02529	-13.09
382.702	1.07	35.9	0.02211	0.02533	-12.71
383.003	1.09	36.5	0.02211	0.02537	-12.84
383.320	1.17	39.3	0.02207	0.02543	-13.21
383.661	1.16	39.0	0.02224	0.02546	-12.65
382.453	0.90	29.8	0.02195	0.02525	-13.09
382.758	0.90	29.8	0.02201	0.02529	-12.96
383.102	0.90	29.8	0.02206	0.02532	-12.89
383.462	0.90	29.7	0.02207	0.02536	-12.98
383.837	0.90	29.7	0.02205	0.02540	-13.20
382.560	0.62	20.2	0.02186	0.02524	-13.41
382.891	0.62	20.2	0.02192	0.02528	-13.29
383.248	0.62	20.2	0.02206	0.02532	-12.87
383.622	0.62	20.2	0.02201	0.02536	-13.20
384.007	0.62	20.2	0.02209	0.02540	-13.03
382.498	0.36	11.3	0.02200	0.02523	-12.80
382.837	0.36	11.3	0.02204	0.02526	-12.76
383.201	0.36	11.3	0.02201	0.02530	-13.02
383.585	0.36	11.3	0.02206	0.02534	-12.96
383.992	0.36	11.3	0.02205	0.02539	-13.15
382.636	0.21	6.5	0.02199	0.02524	-12.88
382.994	0.21	6.5	0.02193	0.02528	-13.25
383.377	0.21	6.5	0.02206	0.02532	-12.87
383.793	0.21	6.5	0.02209	0.02536	-12.91
384.226	0.21	6.5	0.02220	0.02541	-12.63
382.806	0.10	3.2	0.02195	0.02526	-13.09
383.183	0.10	3.2	0.02210	0.02530	-12.64
383.603	0.10	3.2	0.02206	0.02534	-12.95
384.037	0.10	3.2	0.02217	0.02539	-12.68

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
384.493	0.10	3.2	0.02218	0.02544	-12.81
331.883	3.93	873.9	0.05056	0.05400	-6.37
332.077	3.93	872.3	0.05033	0.05393	-6.68
332.268	3.93	870.6	0.05043	0.05386	-6.37
332.460	3.93	868.8	0.05032	0.05378	-6.43
332.680	3.92	866.5	0.05011	0.05368	-6.66
331.893	3.43	853.1	0.04949	0.05313	-6.85
332.074	3.43	851.2	0.04951	0.05306	-6.68
332.271	3.42	848.8	0.04939	0.05296	-6.75
332.474	3.42	846.4	0.04931	0.05288	-6.74
332.686	3.42	844.1	0.04948	0.05279	-6.28
331.472	3.14	842.9	0.04908	0.05277	-6.99
331.632	3.14	841.0	0.04915	0.05270	-6.74
331.818	3.13	838.5	0.04908	0.05262	-6.72
331.983	3.13	836.2	0.04889	0.05254	-6.96
332.176	3.13	833.9	0.04887	0.05247	-6.86
331.470	2.92	829.9	0.04862	0.05238	-7.18
331.629	2.92	827.7	0.04881	0.05232	-6.71
331.804	2.92	825.2	0.04873	0.05225	-6.73
331.990	2.92	822.1	0.04828	0.05217	-7.45
332.178	2.92	819.2	0.04845	0.05209	-7.00
401.986	19.19	834.2	0.05515	0.05670	-2.73
402.170	19.20	833.7	0.05513	0.05668	-2.74
402.372	19.20	833.0	0.05475	0.05667	-3.38
402.589	19.20	832.3	0.05511	0.05664	-2.71
402.814	19.19	831.4	0.05480	0.05662	-3.21
402.062	16.55	789.8	0.05226	0.05439	-3.92
402.254	16.55	789.1	0.05238	0.05438	-3.68
402.472	16.56	788.3	0.05209	0.05436	-4.17
402.689	16.56	787.5	0.05231	0.05434	-3.73
402.925	16.55	786.4	0.05234	0.05430	-3.62
401.955	14.20	739.1	0.04969	0.05204	-4.51
402.145	14.21	738.3	0.04971	0.05202	-4.44
402.364	14.21	737.4	0.04934	0.05200	-5.11
402.571	14.21	736.6	0.04945	0.05198	-4.86
402.808	14.21	735.4	0.04955	0.05195	-4.61
402.028	12.39	686.2	0.04710	0.04987	-5.56
402.230	12.39	685.2	0.04710	0.04985	-5.52
402.456	12.40	684.2	0.04678	0.04983	-6.12
402.691	12.40	683.1	0.04720	0.04980	-5.23
402.925	12.40	682.0	0.04713	0.04978	-5.32
401.908	11.06	635.9	0.04490	0.04802	-6.50
402.133	11.06	634.8	0.04503	0.04800	-6.18
402.336	11.06	633.7	0.04506	0.04797	-6.07
402.559	11.06	632.5	0.04472	0.04795	-6.73
402.809	11.06	630.9	0.04494	0.04791	-6.20

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
401.974	10.01	584.6	0.04289	0.04631	-7.39
402.206	10.01	583.3	0.04317	0.04628	-6.73
402.420	10.01	582.1	0.04286	0.04626	-7.34
402.657	10.02	580.7	0.04289	0.04622	-7.21
402.913	10.02	579.1	0.04281	0.04619	-7.31
401.977	9.16	533.3	0.04090	0.04468	-8.46
402.129	9.16	532.2	0.04112	0.04465	-7.91
402.324	9.16	531.1	0.04138	0.04463	-7.27
402.495	9.16	530.1	0.04088	0.04460	-8.35
402.667	9.16	529.2	0.04083	0.04458	-8.41
402.054	8.45	481.9	0.03920	0.04302	-8.89
402.215	8.44	480.8	0.03932	0.04299	-8.55
402.422	8.44	479.5	0.03902	0.04296	-9.17
402.606	8.45	478.5	0.03890	0.04293	-9.40
402.800	8.45	477.4	0.03910	0.04291	-8.87
402.000	7.84	434.2	0.03753	0.04139	-9.32
402.182	7.84	433.2	0.03744	0.04136	-9.47
402.363	7.84	432.3	0.03743	0.04133	-9.44
402.545	7.84	431.4	0.03723	0.04130	-9.86
402.734	7.84	430.3	0.03708	0.04127	-10.16
401.936	7.26	386.3	0.03543	0.03960	-10.54
402.145	7.26	385.2	0.03546	0.03957	-10.39
402.310	7.26	384.5	0.03545	0.03955	-10.37
402.494	7.26	383.7	0.03546	0.03953	-10.29
402.701	7.26	382.7	0.03526	0.03950	-10.73
402.116	6.69	338.1	0.03362	0.03770	-10.83
402.300	6.69	337.3	0.03363	0.03768	-10.75
402.501	6.69	336.4	0.03358	0.03765	-10.81
402.711	6.69	335.5	0.03359	0.03763	-10.72
402.930	6.69	334.7	0.03351	0.03760	-10.89
402.243	6.11	291.9	0.03176	0.03580	-11.29
402.457	6.11	291.2	0.03189	0.03579	-10.89
402.677	6.11	290.4	0.03171	0.03577	-11.35
402.902	6.11	289.6	0.03166	0.03575	-11.44
403.140	6.11	288.9	0.03174	0.03574	-11.19
402.162	5.48	245.9	0.02960	0.03390	-12.69
402.369	5.48	245.5	0.02961	0.03390	-12.66
402.593	5.48	245.0	0.02964	0.03390	-12.57
402.828	5.48	244.3	0.02965	0.03389	-12.51
403.082	5.47	243.7	0.02957	0.03388	-12.73
402.322	4.68	194.4	0.02809	0.03191	-11.98
402.578	4.68	194.2	0.02803	0.03193	-12.20
402.808	4.68	193.8	0.02811	0.03193	-11.98
403.077	4.68	193.3	0.02799	0.03194	-12.37
403.335	4.68	192.8	0.02801	0.03195	-12.32
402.570	3.78	144.7	0.02651	0.03023	-12.30
402.818	3.78	144.6	0.02656	0.03025	-12.20
403.085	3.78	144.5	0.02652	0.03027	-12.40

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
403.385	3.78	144.3	0.02656	0.03030	-12.34
403.694	3.78	143.9	0.02655	0.03032	-12.43
402.555	2.71	95.5	0.02511	0.02865	-12.34
402.847	2.71	95.3	0.02509	0.02867	-12.50
403.128	2.71	95.3	0.02525	0.02871	-12.04
403.438	2.72	95.3	0.02515	0.02874	-12.49
403.764	2.72	95.2	0.02524	0.02878	-12.29
402.894	1.44	46.5	0.02428	0.02772	-12.42
403.205	1.45	46.6	0.02439	0.02776	-12.14
403.536	1.45	46.6	0.02435	0.02780	-12.41
403.902	1.45	46.6	0.02437	0.02784	-12.47
404.269	1.45	46.6	0.02434	0.02788	-12.70
402.663	1.13	35.5	0.02427	0.02754	-11.86
402.995	1.13	35.8	0.02415	0.02758	-12.43
403.333	1.15	36.1	0.02421	0.02762	-12.35
403.666	1.16	36.4	0.02434	0.02766	-12.01
404.063	1.14	35.8	0.02422	0.02770	-12.56
402.985	0.47	14.2	0.02421	0.02745	-11.79
403.323	0.47	14.1	0.02445	0.02748	-11.03
402.572	0.47	14.3	0.02423	0.02740	-11.57
402.891	0.47	14.2	0.02427	0.02744	-11.54
403.219	0.47	14.2	0.02424	0.02747	-11.76
403.595	0.47	14.2	0.02418	0.02751	-12.11
403.975	0.47	14.2	0.02438	0.02755	-11.52
402.659	0.31	9.4	0.02422	0.02741	-11.63
402.995	0.31	9.4	0.02430	0.02744	-11.46
403.347	0.31	9.4	0.02438	0.02748	-11.29
403.723	0.31	9.4	0.02431	0.02752	-11.68
404.125	0.31	9.4	0.02443	0.02757	-11.38
402.759	0.21	6.3	0.02438	0.02742	-11.08
403.084	0.21	6.3	0.02457	0.02745	-10.50
403.452	0.21	6.3	0.02442	0.02749	-11.18
403.870	0.21	6.3	0.02435	0.02754	-11.58
404.292	0.21	6.3	0.02448	0.02758	-11.25
402.900	0.11	3.1	0.02433	0.02743	-11.31
403.271	0.11	3.1	0.02432	0.02747	-11.47
403.673	0.11	3.1	0.02439	0.02752	-11.36
404.111	0.11	3.1	0.02448	0.02756	-11.19
404.533	0.11	3.1	0.02444	0.02761	-11.48

Table 11. Thermal conductivity for R507A (continued)

Temperature (K)	Pressure (MPa)	Density (calc) (kg/m ³)	λ_{exp} (W/m·K)	λ_{calc} (W/m·K)	$\Delta\lambda$ (%)
302.386	0.30	12.2	0.01439	0.01711	-15.89
302.802	0.29	11.8	0.01440	0.01715	-16.02
303.257	0.28	11.5	0.01439	0.01719	-16.29
303.724	0.27	11.1	0.01442	0.01723	-16.33
304.236	0.26	10.8	0.01444	0.01728	-16.45
302.312	0.10	4.2	0.01480	0.01709	-13.40
302.746	0.10	4.1	0.01482	0.01713	-13.49
303.203	0.10	4.1	0.01478	0.01717	-13.94
303.681	0.10	4.1	0.01477	0.01722	-14.23
304.204	0.10	4.1	0.01476	0.01727	-14.54
317.168	0.30	11.7	0.01552	0.01854	-16.27
317.537	0.30	11.7	0.01560	0.01857	-16.00
317.930	0.30	11.6	0.01560	0.01861	-16.18
318.342	0.30	11.6	0.01560	0.01865	-16.36
318.790	0.30	11.5	0.01564	0.01869	-16.34
317.285	0.21	7.9	0.01560	0.01854	-15.87
317.660	0.21	7.9	0.01563	0.01858	-15.87
318.064	0.20	7.8	0.01565	0.01862	-15.94
318.490	0.20	7.8	0.01565	0.01866	-16.13
318.955	0.20	7.8	0.01568	0.01871	-16.17
317.079	0.10	4.0	0.01582	0.01852	-14.57
317.455	0.10	4.0	0.01582	0.01856	-14.74
317.857	0.11	4.0	0.01582	0.01859	-14.92
318.294	0.10	4.0	0.01582	0.01864	-15.12
318.769	0.10	3.9	0.01582	0.01868	-15.33
331.927	0.30	11.3	0.01685	0.01999	-15.73
332.263	0.30	11.2	0.01692	0.02003	-15.52
332.609	0.30	11.2	0.01691	0.02006	-15.71
332.994	0.30	11.2	0.01691	0.02010	-15.88
333.381	0.30	11.2	0.01698	0.02014	-15.69
332.021	0.20	7.4	0.01694	0.02000	-15.30
332.362	0.20	7.4	0.01692	0.02003	-15.54
332.745	0.20	7.4	0.01693	0.02007	-15.65
333.131	0.20	7.3	0.01693	0.02011	-15.82
333.540	0.20	7.3	0.01696	0.02015	-15.84
332.157	0.10	3.7	0.01703	0.02001	-14.90
332.526	0.10	3.7	0.01701	0.02005	-15.15
332.940	0.10	3.7	0.01703	0.02009	-15.23
333.342	0.10	3.7	0.01706	0.02013	-15.25
333.789	0.10	3.7	0.01705	0.02017	-15.49

7. MIXTURE VISCOSITY MEASUREMENTS

Experimental. Viscosity measurements of the blends R507A and R410A were carried out in the torsional crystal viscometer at two subcritical and three supercritical isotherms with pressures up to 82 MPa. The subcritical measurements were conducted at the nominal temperatures 300 K (liquid only) and 340 K (liquid and vapor). Supercritical measurements included the nominal temperatures 360 K, 390 K, and 420 K.

As described in Sections 4 and 6, the mixtures were prepared gravimetrically using high-purity components. The actual composition of the R410A (R32/125) cylinder used in the viscosity measurements was 0.50001/0.49999 mass fraction, and that of the R507A (R125/143a) was 0.49983/0.50017 mass fraction. The uncertainties in compositions are ± 0.00002 mass fraction.

The majority of the measurements were carried out in a torsional crystal viscometer. The measuring element in this instrument is a cylindrical quartz crystal immersed in the fluid of interest. The crystal is caused to oscillate in a torsional motion at its resonant frequency by an applied electric field. The resonant frequency and the bandwidth of the resonance depend on the viscosity-density product of the surrounding fluid. The technique and the details of the instrument are given by Diller and Frederick (1989).

The working equation for absolute viscosity measurements with the torsional crystal viscometer in the frequency domain is given by

$$\eta \times \rho = \left(\frac{m}{S} \right)^2 (\pi f^*)^2 \left(\frac{\Delta f}{f^*} - \frac{\Delta f_0}{f_0^*} \right)^2. \quad (17)$$

Here, η denotes the viscosity and ρ the density of the fluid; m and S are the mass and surface area of the crystal; f^* is the resonant frequency and Δf is the bandwidth of the resonance. Subscript 0 indicates vacuum conditions. Since this technique measures the viscosity-density product ($\eta \times \rho$), the density of the fluid must be obtained separately in order to determine the viscosity. Thus, the uncertainty of the density propagates directly into the uncertainty of the viscosity measurement. In this work, densities of the refrigerant blends were calculated for the measured pressures and temperatures with REFPROP (Lemmon et al. 2002). The estimated uncertainty in density is $\pm 0.1\%$.

The viscosity measurements were carried out with the cylindrical quartz crystal denoted as “crystal D” (diameter $d = 3.046$ mm, length $L = 50.076$ mm, mass $m = 0.9662$ g) in the transducer of the viscometer. The resonance of the crystal *in vacuo* depends on the applied voltage to drive the torsional crystal vibration and on temperature. The change of the resonant frequency f_0^* and of the resonance bandwidth Δf_0 with these variables was measured after the measurements of the refrigerant blends with drive voltages from 5 mV to 1.1 V in the temperature range from 300 K to 460 K. The results confirmed previous similar measurements in 1996 and in 1998 which indicates a remarkable long-term stability of the transducer. The data from the vacuum measurements of the transducer were correlated for each drive voltage by polynomials in temperature. The resonant frequency f_0^* follows closely a quadratic polynomial with a maximum at approximately 369 K. The logarithm of the bandwidth Δf_0 can be regressed in terms of a cubic polynomial in temperature. These correlations were used in the analysis of the measurements of the refrigerant blends. The accurate determination of the voltage and temperature dependence of the crystal vibration *in vacuo* made it possible to expand the range of operation of the viscometer from saturated or compressed liquids to dilute gases, thus covering a wide range of fluid states with one transducer.

The measurement sequence was designed to use the limited amount of sample as economically as possible. It began by condensing sample from the aluminum supply cylinders through the heated filling system of the viscometer into the stainless-steel high pressure measuring cell which was cooled with liquid nitrogen to less than 200 K. The filling of the cell could be monitored by setting the impedance analyzer to 39 kHz and reading the complex admittance $Y = G + jB$ of the torsional crystal transducer in the cell. The susceptance B indicates the permittivity of the dielectric between the electrodes of the transducer. The reference is its well-established value $B_0 = 34.17 \mu\text{S}$ *in vacuo*. When the transducer was fully immersed in liquid, the cell was returned to 300 K and the maximum pressure by isochoric heating. The semi-automated viscometer was programmed with the desired target pressures, and it carried out the measurements at constant temperature under computer control to a pressure near saturation. The cell was then heated to 420 K to raise the pressure to the starting pressure for that isotherm. When completed, the viscometer was refilled for each of the remaining isotherms at 340 K, 360 K, and 390 K.

Of the refrigerant blends in this work, R507A was measured first and R410A second. The measurement protocol for fluids comprises frequency scans of the transducer resonance in the sample fluid with varying drive voltages at every pressure of each isotherm. Resolving the dependence of the resonance on the drive voltage allows extrapolation to the resonance at zero drive voltage which is consistent with the definition of Newtonian viscosity as a property characterizing momentum transport in the limit of zero shear. Due to the resolution limits of the impedance analyzer used with the instrument, the majority of the measurements was limited to drive voltages from 0.1 V to 1.1 V. Lower voltages to 10 mV could be applied only in a few cases of dilute gases. For reasons of consistency, all the results reported in this work were derived from resonance scans with drive voltages of 0.1 V. The uncertainty of measurements with the torsional crystal viscometer typically does not exceed $\pm 2\%$.

The experimental viscosities measured with the torsional crystal viscometer were compared with viscosities calculated with the extended corresponding states model implemented in REFPROP (i.e., the model of Klein et al. 1997). They were also compared with literature data. In the following, the results will be presented for each blend and their reliability will be discussed.

Results for R507A. The impedance analyzer used with the instrument can also provide a measurement of the conductance G (measured in units of Siemens) at the resonant frequency of approximately 39 kHz. Examination of the conductance values is important for polar fluids, such as the HFC refrigerants, because measurements of fluids with a high background conductance ($G > 1 \mu\text{S}$) may be influenced by electroviscous effects because the sample fluid is exposed to the applied drive voltage.

Figure 10 shows the measured conductances G at 39 kHz of the blend R507A as a function of density. Any increase of the conductance beyond that of the instrument circuitry under vacuum indicates the presence of charge carriers in the sample. No increase of the conductances of R507A occurs up to a density of about 500 kg/m^3 . At higher densities the conductances increase with both density and temperature. While the increase is monotone at 360 K and above, a flattening is observed on the isotherms at 300 K and 340 K beginning at about 1100 kg/m^3 . The highest conductance of $G = 0.62 \mu\text{S}$ was measured at the highest pressure of the 390 K-isotherm. The scatter of the conductances at 360 K was caused by intermittent problems with an electrical connection in the instrument circuitry.

The viscosities for the blend R507A that were measured in the torsional crystal viscometer are tabulated in Table 12. Their density dependence is displayed in Figure 11. Due to the measurements at supercritical temperatures they cover the entire density range from 0.09 kg/m^3 to 1300 kg/m^3 . Figure 11 shows that the viscosity data aggregate along a single line with a barely discernible temperature dependence. The weak temperature dependence is revealed when the

measured viscosities are compared with data that are calculated with the extended corresponding states model in REFPROP. Figure 12 illustrates the percent deviations between experimental and calculated viscosities of R507A. A significant systematic deviation with density is observed. Smaller systematic deviations from isotherm to isotherm are also seen. The scatter from point to point along a given isotherm are well within the ± 2 uncertainty of the measurements. These results reveal a deficiency in the extended corresponding states model.

The present measurements constitute a significant improvement of our knowledge of the viscosity of R507A. This is documented in Figure 13 which compares the previously available literature data of the binary system R143a + R125 with the extended corresponding states model in REFPROP. The saturated liquid measurements of Heide and Schenk (1996) deviate from the calculated viscosities between -4.5% and 15% . The gas measurements of Nabizadeh and Mayinger (1999) exhibit the same systematic deviations that exist in all their results. They agree with the calculated data only in the limit of zero density and show increasing deviations up to 14% with increasing density. The surface light scattering measurements of Fröba et al. (2001) on saturated liquid R507A deviate from the calculated data between -9.3% and 3.8% . In summary, all literature data for R507A deviate from the calculated viscosities more than their estimated uncertainties which suggests that these measurements were affected by systematic errors.

Results for R410A. Figure 14 shows the measured conductances G at 39 kHz of the blend R410A as a function of density. As in the case of R507A no increase of the conductances occurs in R410A up to a density of about 500 kg/m^3 . At higher densities the conductances of R410A are in strong contrast to the low levels observed in R507A (Figure 10). The density and temperature dependence is much more pronounced and the highest measured conductance of $G = 5.72\text{ }\mu\text{S}$ at 420 K and 1050 kg/m^3 is more than nine times higher than the highest conductance measured in R507A. This observation is consistent with our previous studies of pure R32 and of binary systems that contained R32. Elevated electrical conductances were observed in all cases, the reasons of which have not yet been identified in detail.

Based on molecular dynamics simulations, Lísal and Vacek (1996) suggested that the polar R32 molecules associate closely in the liquid state via H-F bonds. It is not clear if these associations are strong enough to enable electrical conduction via electron transport. Rather, the electrical conductances observed in our studies indicate the presence of a significant amount of charge carriers in fluids containing R32. Sample contaminations with ionic impurities can be largely excluded as the reason for these conductances because our studies used samples that were independently prepared from various pure fluids, at different times, and in different containers. Thus the charge carriers must originate from the R32 itself by dissociation. Unfortunately, no other quantitative investigations have been carried out that would help to elucidate molecular interactions in fluids containing R32. Barão et al. (1997) and Abbott et al. (1999) measured permittivities of hydrofluorocarbons including R32. Suspiciously, both reports contain complete results only for the other compounds studied but not for R32.

In conclusion, the elevated electrical conductances of R410A that were measured in this work indicate the presence of charge carriers in the sample. The presence of polar molecules and charge carriers influences the operation of the torsional crystal viscometer on two counts. First, the charge carriers follow the applied ac voltage that is transmitted from the electrodes across the fluid sample to drive the torsional vibration of the piezoelectric crystal. Relaxation times of molecular reorientations on the order of picoseconds are much shorter than the period of the alternating voltage which is in the millisecond range. Secondly, the charge carriers are alternately attracted and repelled by the oscillating surface charge of the piezoelectric crystal that is generated by its torsional mechanical deformation. This generates a secondary flow perpendicular to the crystal surface that is superimposed to the primary shear flow of the sample fluid tangential to the crystal surface. The secondary flow adds an electroviscous component to

the friction in the fluid which increases with the number of charge carriers. Consequently, viscosities measured with the torsional crystal viscometer on electrically conducting fluids are systematically higher than viscosities measured in instruments where the sample is not exposed to an alternating electric field. The systematic deviations are directly proportional to the number of charge carriers which in turn is characterized by the measured electrical conductance.

The viscosities measured in the torsional crystal viscometer are tabulated in Table 13. Their density dependence is displayed in Figure 15; the saturated liquid measurements are from the measurements in the capillary viscometer described below.

For R410A, the temperature dependence of the viscosity is more noticeable than in the results for R507A. A magnified view is offered in the deviation plot, Figure 16. As with R507A, there are strong systematic deviations between the data and the extended corresponding states model. For R410A, the temperature dependence is somewhat more complicated. In addition to deficiencies in the mixture model, the larger deviations for R410A compared to R507A may be due to the increase of the electrical conductances (Figure 14). The experimental results represent the combined effect of molecular friction and electroviscous friction but the working theory of the instrument accounts only for molecular friction.

To corroborate these results, the viscosity of the refrigerant blend R410A was also measured in a sealed gravitational capillary viscometer between 242 K and 320 K. This instrument measures the viscosity of the saturated liquid. It is described in detail by Laesecke et al. (1999). The viscometer was recalibrated by measurements on toluene at 320, 335, and 350 K. The calibration constant obtained was $C_1 = (6.277 \pm 0.067) \cdot 10^{-12} \text{ m}^3/\text{s}^2$. This value is consistent with our earlier calibrations of this instrument. The calculations were based on the measured bulk density $\rho_{\text{bulk}} = 343.4 \text{ kg/m}^3$ of the sample in the viscometer. The contribution of the uncertainty of the bulk density to the experimental uncertainty of the viscosity measurements was assessed by comparing the calculated sample properties at the measured bulk density with those at bulk densities 10% below and above that value. The resulting variations in the saturated liquid and vapor density ranged from -0.014 % to 0.017 % and from -0.055 % to 0.067 %, respectively. Thus, the data analysis is rather insensitive to the uncertainty of the bulk density. The expanded uncertainty of the present measurements is estimated at ± 2.4 % (coverage factor of 2), the same level as in our previous measurements of the similar system R32 + R134a.

The results from the capillary viscometer are presented in Table 14 and depicted in Figure 15. This table gives the experimental temperatures and the estimated densities of saturated liquid and vapor that were calculated using REFPROP. Also included are viscosities calculated with the extended corresponding states model of Klein et al. (1997) (i.e., the model in REFPROP) and the percent deviations between the experimental results and the calculated data. Systematic deviations as a function of density are revealed in Figure 16. But, again, the point-to-point scatter of the data are small.

Deviations of literature data for the viscosity of the binary system R32 + R125 are shown in Figure 17 relative to data calculated with the extended corresponding states model in REFPROP. The first measurements of a mixture of 0.6 R32 + 0.4 R125 (by mass) with a reported uncertainty of ± 1.2 % were published by Bivens et al. (1993). Figure 17 shows agreement between these data and the predicted viscosities within the uncertainty estimate except for the data point at 253.15 K which deviates by about 5 %. Heide and Schenk (1996) measured three binary blends at mass fractions of R32 of 0.753, 0.51, and 0.251 with a falling-body viscometer. The uncertainty was reported to be $\pm 2\%$ for a viscosity of 0.2 mPa·s. This corresponds to the viscosity of saturated liquid R410A at approximately 259 K. The results of Heide and Schenk do agree with the predicted viscosities within that margin and at such temperatures. However, the deviations increase to almost -4 % at lower temperatures and to -18 % at temperatures above 313 K. Two laboratories reported measurements in the gas region with oscillating disk

viscometers. The results of Nabizadeh and Mayinger (1999) exhibit similar systematic density deviations as their data for R507A (Figure 13) except the limiting value at zero density is offset by about -3% . Even higher deviations are displayed by their saturated vapor data which are extrapolated from their measurements. The appropriateness of the extrapolation method appears questionable. On the other hand, their results are supported by the measurements of Yokoyama et al. (2001) which exhibit almost congruent deviations from the calculated viscosities. This agreement between independent results of two laboratories suggests that the extended corresponding states model in REFPROP does not capture correctly the molecular interactions in the binary system R32 + R125.

The present work contributes a substantial number of new data that fills the existing data gap for this binary system in the density range from 300 kg/m^3 to 800 kg/m^3 . The negative deviations below 300 kg/m^3 are consistent with the results of the oscillating disk measurements of Nabizadeh and Mayinger (1999) and of Yokoyama et al. (2001). They will contribute to the refinement of the mixture model in REFPROP. The results in the liquid and compressed liquid region (at densities above 900 kg/m^3 for the isotherms 300 K to 390 K and above 700 kg/m^3 at 420 K) form the basis to extend the working theory of the torsional crystal viscometer to electrically conducting fluids.

Figure 10. Conductances G at 39 kHz of the mixture R507A (0.5 R143a + 0.5 R125 by mass) as measured in the torsional crystal viscometer.

Figure 11. Density dependence of experimental viscosities of the mixture R507A (0.5 R143a + 0.5 R125 by mass) as measured in the torsional crystal viscometer.

Figure 12. Percent deviations between experimental viscosities of the mixture R507A (0.5 R143a + 0.5 R125 by mass) as measured in the torsional crystal viscometer and data calculated with the model in REFPROP.

Figure 13. Percent deviations between literature data for the viscosity of the binary system R143a + R125 and data calculated with the model in REFPROP.

Figure 14. Conductances G at 39 kHz of the mixture R410A (0.5 R32 + 0.5 R125 by mass) as measured in the torsional crystal viscometer.

Figure 15. Density dependence of experimental viscosities of the mixture R410A (0.5 R32 + 0.5 R125 by mass) as measured in the torsional crystal and capillary viscometers.

Figure 16. Percent deviations between experimental viscosities of the mixture R410A (0.5 R32 + 0.5 R125 by mass) as measured in the torsional crystal viscometer and in the sealed gravitational capillary viscometer and data calculated with the model in REFPROP.

$$100 (\eta_{lit} / \eta_{REFPROP} - 1)$$

- ◆ Bivens et al. 1993, Sat. Liq., w(R32) = 0.6
- ▲ Nabizadeh, Mayinger 1999, R410A
- ▲ Nabizadeh, Mayinger 1999, Sat. Vap., R410A
- Heide, Schenk 1996, Sat. Liq., w(R32) = 0.753
- Heide, Schenk 1996, Sat. Liq., w(R32) = 0.51
- Heide, Schenk 1996, Sat. Liq., w(R32) = 0.256
- Yokoyama et al. 2001, w(R32) = 0.1263
- Yokoyama et al. 2001, w(R32) = 0.3026
- Yokoyama et al. 2001, w(R32) = 0.5686

Figure 17. Percent deviations between literature data for the viscosity of the binary system R32 + R125 and data calculated with the in REFPROP.

Table 12. Experimental viscosities of the mixture R507A (0.5 R143a + 0.5 R125 by mass) as measured in the torsional crystal viscometer. Each line represents the average of four measurements. The precision of the measurements is indicated by the relative standard deviation of the pressure averaging, s_p/p , and of the viscosity averaging, s_η/η . Calculated densities and viscosities were obtained from REFPROP. Percent differences between experimental and calculated viscosities are listed in the column $\Delta\eta$.

T (K)	P (MPa)	η (mPa·s)	s_p/P (%)	s_η/η (%)	ρ_{calc} (kg/m ³)	η_{calc} (mPa·s)	$\Delta\eta$ (%)
301.29	66.852	0.2925	0.03	0.73	1299.52	0.2731	7.10
300.79	54.147	0.2662	0.02	0.82	1273.14	0.2485	7.11
300.52	41.734	0.2396	0.01	0.32	1242.39	0.2232	7.35
300.33	31.904	0.2157	0.07	0.29	1213.25	0.2022	6.67
300.15	23.731	0.1969	0.07	0.63	1184.21	0.1861	5.78
299.99	16.841	0.1763	0.09	0.30	1154.41	0.1699	3.78
299.85	11.202	0.1599	0.12	0.32	1124.12	0.1556	2.81
299.74	6.595	0.1457	0.13	0.26	1092.55	0.1425	2.25
299.66	3.575	0.1345	1.99	0.56	1065.97	0.1329	1.20
340.65	67.754	0.2239	0.00	0.34	1229.76	0.2050	9.24
340.65	52.722	0.1961	0.01	0.24	1189.96	0.1809	8.37
340.66	44.042	0.1805	0.01	0.42	1162.33	0.1664	8.49
340.65	38.680	0.1689	0.01	0.48	1142.85	0.1570	7.56
340.64	31.652	0.1538	0.00	0.16	1113.38	0.1441	6.71
340.66	25.845	0.1414	0.04	0.83	1084.16	0.1326	6.65
340.65	20.764	0.1297	0.02	0.10	1053.24	0.1242	4.43
340.65	16.782	0.1187	0.00	0.39	1023.46	0.1153	3.01
340.66	13.648	0.1097	0.01	0.13	994.57	0.1074	2.15
340.66	11.013	0.1013	0.01	0.20	964.32	0.1000	1.31
340.67	8.961	0.0941	0.02	0.10	934.39	0.0934	0.69
340.66	7.292	0.0864	0.02	0.17	903.00	0.0871	-0.84
340.67	6.043	0.0795	0.00	0.16	871.73	0.0814	-2.33
340.65	5.204	0.0750	0.03	0.27	843.88	0.0767	-2.22
340.66	4.437	0.0686	0.04	0.14	807.74	0.0712	-3.70
340.66	3.986	0.0624	0.03	0.18	775.68	0.0667	-6.46
340.65	3.686	0.0576	0.05	0.19	742.02	0.0624	-7.74
340.66	3.485	0.0525	0.03	0.14	697.77	0.0572	-8.20
340.65	3.059	0.0169	0.04	0.14	188.51	0.0197	-14.20
340.66	2.767	0.0163	0.06	0.85	152.62	0.0185	-11.98
340.66	2.394	0.0153	0.09	1.75	119.18	0.0175	-12.82
340.68	2.053	0.0146	0.45	1.12	94.93	0.0169	-13.86
340.66	1.598	0.0146	0.02	0.57	68.18	0.0162	-9.74
340.67	1.002	0.0142	0.08	0.61	39.22	0.0156	-9.30
340.66	0.266	0.0140	0.00	0.27	9.54	0.0152	-7.77
340.66	0.138	0.0140	0.01	0.47	4.88	0.0151	-7.28

Table 12. Experimental viscosities of the mixture R507A (continued).

T (K)	P (MPa)	η (mPa·s)	s_p/P (%)	s_η/η (%)	ρ_{calc} (kg/m ³)	η_{calc} (mPa·s)	$\Delta\eta$ (%)
360.73	41.677	0.1529	0.03	0.52	1110.22	0.1418	7.80
360.64	35.317	0.1425	0.04	0.47	1082.21	0.1312	8.55
360.59	30.070	0.1310	0.05	0.61	1054.95	0.1219	7.43
360.57	25.406	0.1202	0.04	0.25	1026.16	0.1130	6.45
360.58	21.176	0.1100	0.01	0.26	994.51	0.1064	3.41
360.58	15.366	0.0944	0.01	0.19	936.42	0.0929	1.63
360.57	13.105	0.0877	0.01	0.03	905.60	0.0867	1.07
360.58	11.389	0.0816	0.01	0.20	876.48	0.0814	0.26
360.58	9.808	0.0747	0.00	0.00	842.62	0.0756	-1.28
360.59	8.833	0.0701	0.02	0.16	816.18	0.0715	-2.02
360.56	7.799	0.0646	0.01	0.34	780.60	0.0664	-2.73
360.59	7.240	0.0607	0.01	0.33	755.45	0.0631	-3.73
360.59	6.723	0.0567	0.01	0.23	726.51	0.0594	-4.58
360.59	6.306	0.0526	0.00	0.16	696.39	0.0559	-5.89
360.60	6.035	0.0499	0.00	0.14	671.32	0.0531	-6.07
360.57	5.722	0.0454	0.00	0.27	634.13	0.0493	-7.87
360.58	5.494	0.0417	0.00	0.34	596.54	0.0456	-8.62
360.57	5.379	0.0396	0.00	0.14	572.97	0.0435	-8.88
360.58	5.262	0.0371	0.00	0.17	544.12	0.0410	-9.58
360.60	5.121	0.0340	0.00	0.26	502.76	0.0376	-9.62
360.58	5.022	0.0317	0.00	0.10	471.38	0.0353	-9.98
360.59	4.938	0.0301	0.00	0.17	443.28	0.0333	-9.36
360.59	4.839	0.0279	0.01	0.05	411.23	0.0311	-10.26
360.59	4.766	0.0265	0.00	0.12	388.95	0.0297	-10.90
360.59	4.650	0.0247	0.01	0.31	356.71	0.0279	-11.22
360.57	4.547	0.0233	0.02	0.14	331.69	0.0265	-12.11
360.58	4.421	0.0221	0.01	0.07	304.54	0.0251	-12.21
360.60	4.306	0.0211	0.01	0.20	282.88	0.0241	-12.34
360.59	4.064	0.0198	0.01	0.08	245.23	0.0225	-11.91
360.59	3.885	0.0191	0.01	0.24	222.13	0.0216	-11.47
360.57	3.294	0.0174	0.03	0.48	163.61	0.0196	-11.09
360.58	2.901	0.0165	0.04	0.38	133.88	0.0187	-11.77
360.58	2.498	0.0159	0.05	0.23	108.11	0.0180	-11.78
360.59	1.980	0.0153	0.09	0.79	79.81	0.0172	-11.02
360.49	1.331	0.0149	0.01	0.09	49.76	0.0166	-10.36
360.56	0.565	0.0144	0.01	0.04	19.57	0.0161	-10.70
360.59	0.289	0.0142	0.01	0.22	9.77	0.0160	-10.96

Table 12. Experimental viscosities of the mixture R507A (continued).

T (K)	P (MPa)	η (mPa·s)	s_p/P (%)	s_η/η (%)	ρ_{calc} (kg/m ³)	η_{calc} (mPa·s)	$\Delta\eta$ (%)
391.03	66.793	0.1685	0.03	0.26	1139.92	0.1527	10.35
390.84	60.494	0.1592	0.04	0.27	1120.44	0.1447	10.04
390.77	53.893	0.1482	0.02	0.25	1097.45	0.1359	9.05
390.78	47.712	0.1379	0.01	0.37	1072.94	0.1273	8.32
390.78	42.065	0.1289	0.01	0.43	1047.40	0.1191	8.26
390.77	37.422	0.1202	0.00	0.25	1023.40	0.1120	7.29
390.78	33.137	0.1126	0.01	0.61	997.98	0.1050	7.16
390.77	29.530	0.1053	0.00	0.10	973.39	0.0988	6.51
390.78	26.357	0.0987	0.01	0.10	948.41	0.0930	6.11
390.77	23.668	0.0924	0.01	0.42	924.03	0.0896	3.07
390.77	20.405	0.0847	0.01	0.37	888.75	0.0829	2.17
390.74	18.896	0.0809	0.01	0.08	869.64	0.0795	1.73
390.76	16.983	0.0753	0.04	0.26	841.50	0.0748	0.58
390.77	15.498	0.0709	0.02	0.13	815.83	0.0709	-0.01
390.77	14.567	0.0680	0.02	0.23	797.47	0.0682	-0.34
390.78	13.206	0.0632	0.03	0.15	766.25	0.0639	-1.18
390.77	12.251	0.0596	0.01	0.23	740.32	0.0606	-1.72
390.78	11.488	0.0567	0.01	0.08	716.14	0.0577	-1.78
390.77	10.796	0.0534	0.00	0.10	690.91	0.0548	-2.65
390.77	10.212	0.0504	0.01	0.18	666.26	0.0522	-3.44
390.78	9.742	0.0484	0.00	0.14	643.54	0.0499	-2.95
390.80	9.349	0.0456	0.00	0.12	622.07	0.0478	-4.54
390.77	8.796	0.0422	0.00	0.24	587.73	0.0446	-5.40
390.78	8.473	0.0402	0.03	0.14	564.56	0.0426	-5.61
390.78	8.179	0.0379	0.02	0.14	541.41	0.0407	-6.83
390.77	7.907	0.0361	0.02	0.25	518.20	0.0389	-7.09
390.78	7.529	0.0335	0.02	0.17	482.84	0.0363	-7.56
390.78	7.085	0.0307	0.02	0.24	437.97	0.0333	-7.60
390.77	6.891	0.0296	0.03	0.17	417.74	0.0320	-7.42
390.76	6.693	0.0284	0.03	0.18	396.96	0.0308	-7.64
390.77	6.394	0.0267	0.01	0.23	365.69	0.0290	-7.98
390.79	6.194	0.0256	0.01	0.18	345.18	0.0279	-8.43
390.78	5.821	0.0238	0.01	0.21	308.80	0.0261	-8.80
390.77	5.618	0.0230	0.00	0.25	290.08	0.0253	-8.94
390.76	5.311	0.0219	0.01	0.20	263.32	0.0241	-9.23
390.78	5.103	0.0213	0.00	0.21	246.19	0.0234	-9.16
390.77	4.787	0.0204	0.02	0.33	221.93	0.0225	-9.51
390.77	4.502	0.0197	0.01	0.11	201.62	0.0218	-9.75
390.78	3.977	0.0189	0.12	0.73	167.73	0.0207	-8.90
390.78	3.604	0.0182	0.02	0.34	146.10	0.0201	-9.55
390.77	3.095	0.0176	0.17	0.39	119.32	0.0194	-9.28
390.79	2.668	0.0169	0.17	0.88	98.89	0.0187	-9.82
390.76	1.985	0.0165	0.17	0.29	69.47	0.0182	-9.17
390.78	1.551	0.0163	0.05	0.11	52.47	0.0178	-8.69
390.78	0.773	0.0159	0.09	0.26	24.73	0.0174	-8.45
390.77	0.632	0.0160	0.01	0.05	20.03	0.0173	-7.50
390.79	0.320	0.0158	0.01	0.19	9.93	0.0171	-7.71
390.78	0.161	0.0158	0.01	0.15	4.95	0.0171	-7.49

Table 12. Experimental viscosities of the mixture R507A (continued).

T (K)	P (MPa)	η (mPa·s)	s_p/P (%)	s_η/η (%)	ρ_{calc} (kg/m ³)	η_{calc} (mPa·s)	$\Delta\eta$ (%)
420.82	52.103	0.1249	0.00	0.35	1034.65	0.1152	8.45
420.88	40.738	0.1062	0.00	0.32	976.84	0.0999	6.22
420.90	34.770	0.0963	0.00	0.36	937.95	0.0911	5.68
420.89	34.756	0.0968	0.01	0.25	937.87	0.0911	6.25
420.91	27.811	0.0832	0.05	0.16	879.74	0.0796	4.47
420.90	23.853	0.0747	0.00	0.11	836.55	0.0723	3.36
420.89	20.410	0.0668	0.01	0.21	788.99	0.0669	-0.14
420.92	17.528	0.0596	0.00	0.13	737.60	0.0602	-1.07
420.91	15.087	0.0526	0.00	0.13	680.91	0.0538	-2.22
420.90	13.329	0.0466	0.01	0.26	628.14	0.0485	-3.89
420.90	12.333	0.0431	0.01	0.13	591.82	0.0452	-4.59
420.92	11.104	0.0389	0.00	0.12	538.62	0.0408	-4.61
420.92	10.076	0.0346	0.00	0.30	486.14	0.0369	-6.31
420.90	9.291	0.0317	0.00	0.17	441.36	0.0340	-6.79
420.93	8.392	0.0288	0.00	0.27	386.20	0.0308	-6.56
420.92	7.574	0.0264	0.00	0.11	334.93	0.0282	-6.12
420.92	6.793	0.0241	0.01	0.12	286.98	0.0260	-7.25
420.92	6.098	0.0227	0.00	0.03	246.42	0.0244	-6.91
420.92	5.122	0.0208	0.02	0.52	194.06	0.0226	-7.88
420.91	3.907	0.0193	0.01	0.20	136.84	0.0207	-6.86
420.93	2.840	0.0185	0.03	0.24	93.21	0.0198	-6.38
420.93	1.609	0.0179	0.04	0.07	49.29	0.0189	-5.40
420.92	0.731	0.0174	0.05	0.10	21.40	0.0184	-5.65
420.91	0.333	0.0177	0.01	0.08	9.56	0.0183	-3.12
420.91	0.090	0.0186	0.02	0.08	2.55	0.0181	2.37

Table 13. Experimental viscosities of the mixture R410A (0.5 R32 + 0.5 R125 by mass) as measured in the torsional crystal viscometer. (Symbols same as Table 12.)

T (K)	P (MPa)	η (mPa·s)	s_p/P (%)	s_η/η (%)	ρ_{calc} (kg/m ³)	η_{calc} (mPa·s)	$\Delta\eta$ (%)
304.72	82.477	0.2653	0.00	0.62	1309.85	0.3284	-19.23
304.79	75.079	0.2552	0.03	0.45	1296.48	0.3098	-17.63
304.80	59.368	0.2280	0.01	0.53	1265.04	0.2711	-15.91
304.84	48.136	0.2104	0.00	0.67	1238.78	0.2434	-13.57
304.87	40.172	0.1986	0.01	0.42	1217.52	0.2237	-11.21
304.87	32.857	0.1842	0.01	0.48	1195.44	0.1734	6.25
304.90	26.608	0.1723	0.02	0.38	1173.78	0.1628	5.85
304.85	20.770	0.1623	0.01	0.35	1150.64	0.1525	6.42
304.78	15.808	0.1512	0.02	0.29	1127.69	0.1433	5.54
304.69	11.463	0.1419	0.04	0.40	1103.95	0.1346	5.45
304.56	7.820	0.1326	0.09	0.00	1080.16	0.1267	4.63
304.43	4.797	0.1243	0.17	0.11	1056.00	0.1194	4.05
304.58	2.530	0.1167	0.12	0.28	1031.89	0.1128	3.46
340.38	67.716	0.1986	0.01	0.22	1208.42	0.2072	-4.12
340.38	56.626	0.1799	0.01	0.33	1179.58	0.1867	-3.68
340.38	49.354	0.1681	0.00	0.39	1157.95	0.1731	-2.93
340.38	42.629	0.1562	0.01	0.21	1135.35	0.1603	-2.58
340.38	36.230	0.1453	0.01	0.37	1110.75	0.1477	-1.66
340.37	32.249	0.1384	0.01	0.33	1093.45	0.1265	9.43
340.37	27.851	0.1303	0.01	0.26	1071.90	0.1198	8.76
340.36	23.520	0.1217	0.01	0.22	1047.42	0.1128	7.89
340.38	20.338	0.1147	0.02	0.40	1026.45	0.1073	6.93
340.38	17.696	0.1087	0.01	0.19	1006.53	0.1024	6.10
340.37	15.043	0.1027	0.01	0.25	983.27	0.0971	5.75
340.36	13.208	0.0971	0.01	0.20	964.49	0.0931	4.31
340.38	11.298	0.0915	0.02	0.39	941.36	0.0885	3.46
340.40	9.774	0.0866	0.04	0.21	919.14	0.0843	2.77
340.36	8.142	0.0802	0.02	0.33	889.73	0.0792	1.19
340.38	7.200	0.0759	0.04	0.35	867.71	0.0757	0.28
340.37	6.586	0.0729	0.03	0.10	850.35	0.0731	-0.31
340.37	5.930	0.0690	0.04	0.08	827.09	0.0697	-1.04
340.37	5.426	0.0661	0.02	0.11	803.49	0.0666	-0.69
340.38	4.398	0.0188	0.00	0.18	249.85	0.0218	-13.84
340.37	4.293	0.0179	0.01	0.26	226.34	0.0209	-14.08
340.36	4.252	0.0177	0.00	0.20	219.00	0.0206	-13.94
340.37	4.102	0.0171	0.02	0.39	196.60	0.0198	-13.63
340.40	3.884	0.0166	0.03	0.41	171.85	0.0190	-12.60
340.38	3.583	0.0162	0.03	0.84	145.79	0.0183	-11.61
340.39	3.341	0.0157	0.03	0.44	128.64	0.0178	-11.57
340.37	3.007	0.0154	0.02	0.46	108.58	0.0173	-11.25
340.36	2.586	0.0151	0.02	0.26	87.23	0.0168	-9.87
340.37	2.084	0.0148	0.00	0.06	65.63	0.0161	-8.01
340.38	1.538	0.0146	0.00	0.09	45.45	0.0158	-7.51
340.38	0.792	0.0143	0.00	0.07	21.73	0.0155	-7.40
340.39	0.287	0.0142	0.01	0.05	7.53	0.0153	-6.80
340.39	0.211	0.0140	0.00	0.04	5.50	0.0152	-8.22

Table 13. Experimental viscosities of the mixture R410A (continued).

T (K)	P (MPa)	η (mPa·s)	s_p/P (%)	s_η/η (%)	ρ_{calc} (kg/m ³)	η_{calc} (mPa·s)	$\Delta\eta$ (%)
340.38	0.141	0.0139	0.00	0.05	3.66	0.0152	-8.83
340.38	0.090	0.0136	0.00	0.12	2.32	0.0152	-10.71
420.81	69.034	0.1460	0.00	0.47	1051.82	0.1213	20.37
420.80	61.517	0.1337	0.01	0.64	1023.88	0.1122	19.10
420.83	57.383	0.1258	0.00	0.17	1006.73	0.1071	17.44
420.82	52.044	0.1157	0.00	0.28	982.43	0.1004	15.27
420.83	47.959	0.1088	0.00	0.39	961.70	0.0951	14.45
420.80	44.321	0.1031	0.00	0.23	941.41	0.0902	14.26
420.80	40.831	0.0970	0.00	0.27	919.79	0.0854	13.53
420.79	37.785	0.0913	0.00	0.18	898.86	0.0811	12.53
420.80	33.742	0.0837	0.00	0.08	867.12	0.0751	11.51
420.82	32.400	0.0809	0.01	0.24	855.31	0.0716	12.96
420.80	29.433	0.0754	0.00	0.35	826.55	0.0676	11.59
420.80	27.494	0.0712	0.00	0.19	805.11	0.0647	9.97
420.80	25.772	0.0675	0.00	0.09	783.85	0.0620	8.86
420.80	24.254	0.0643	0.01	0.18	762.96	0.0595	8.01
420.85	21.360	0.0579	0.01	0.20	715.54	0.0543	6.55
420.83	20.297	0.0555	0.01	0.24	695.09	0.0523	6.18
420.83	19.407	0.0530	0.00	0.19	676.22	0.0504	5.08
420.85	18.478	0.0505	0.00	0.20	654.54	0.0484	4.28
420.74	17.664	0.0487	0.01	0.11	634.30	0.0466	4.44
420.79	17.043	0.0468	0.01	0.01	616.95	0.0452	3.64
420.81	16.368	0.0452	0.00	0.51	596.85	0.0435	3.88
420.81	15.678	0.0434	0.00	0.11	574.73	0.0418	3.87
420.82	14.796	0.0411	0.01	0.23	543.78	0.0395	4.03
420.82	14.209	0.0394	0.01	0.15	521.47	0.0380	3.79
420.84	13.620	0.0376	0.00	0.08	497.59	0.0364	3.31
420.79	12.842	0.0354	0.00	0.20	464.33	0.0344	3.07
420.82	12.135	0.0332	0.01	0.28	431.96	0.0325	2.18
420.80	11.861	0.0325	0.01	0.17	419.18	0.0318	2.19
420.83	11.243	0.0308	0.00	0.11	389.53	0.0303	1.76
420.81	10.848	0.0297	0.01	0.26	370.52	0.0294	0.92
420.87	10.447	0.0291	0.01	0.18	350.90	0.0285	2.05
420.85	10.040	0.0283	0.00	0.16	331.39	0.0276	2.38
420.83	9.630	0.0272	0.01	0.08	311.95	0.0268	1.44
420.84	6.697	0.0228	0.00	0.27	186.64	0.0225	1.27
420.81	5.825	0.0219	0.03	0.33	155.31	0.0216	1.10
420.82	5.247	0.0217	0.09	0.78	135.94	0.0208	4.29
420.80	4.524	0.0213	0.01	0.21	113.23	0.0203	4.61
420.94	1.909	0.0206	0.01	0.18	42.60	0.0191	7.87
420.83	1.309	0.0205	0.00	0.21	28.53	0.0189	8.49
420.78	0.334	0.0226	0.00	0.28	7.02	0.0186	21.68
390.07	66.399	0.1448	0.00	0.36	1103.39	0.1418	2.11
390.07	62.029	0.1396	0.00	0.25	1089.02	0.1357	2.85
390.06	55.814	0.1315	0.00	0.23	1066.65	0.1270	3.59
390.07	50.409	0.1232	0.00	0.35	1044.86	0.1192	3.42

Table 13. Experimental viscosities of the mixture R410A (continued).

T (K)	P (MPa)	η (mPa·s)	s_p/P (%)	s_η/η (%)	ρ_{calc} (kg/m ³)	η_{calc} (mPa·s)	$\Delta\eta$ (%)
390.07	45.592	0.1159	0.01	0.49	1023.19	0.1120	3.42
390.05	41.324	0.1098	0.00	0.18	1001.77	0.1055	4.03
390.06	37.358	0.1038	0.00	0.27	979.33	0.0992	4.56
390.05	34.150	0.0982	0.01	0.23	959.03	0.0898	9.27
390.06	31.118	0.0931	0.01	0.09	937.46	0.0857	8.64
390.06	27.281	0.0858	0.00	0.16	905.84	0.0800	7.31
390.04	25.964	0.0841	0.00	0.34	893.59	0.0779	7.96
390.06	23.307	0.0784	0.01	0.84	865.60	0.0735	6.72
390.07	21.577	0.0741	0.00	0.54	844.51	0.0703	5.35
390.05	19.956	0.0709	0.01	0.00	822.11	0.0672	5.50
390.06	18.621	0.0676	0.01	0.16	800.90	0.0644	4.98
390.05	17.481	0.0644	0.01	0.14	780.40	0.0618	4.19
390.08	16.424	0.0612	0.00	0.13	758.56	0.0592	3.40
390.07	15.465	0.0582	0.00	0.19	736.12	0.0566	2.77
390.04	14.865	0.0559	0.01	0.28	720.51	0.0549	1.77
390.06	14.134	0.0535	0.01	0.29	698.95	0.0527	1.59
390.04	13.459	0.0509	0.01	0.16	676.66	0.0505	0.92
390.05	12.637	0.0478	0.00	0.38	644.96	0.0475	0.75
390.05	12.150	0.0458	0.01	0.20	623.44	0.0456	0.58
390.04	11.768	0.0440	0.00	0.15	604.90	0.0440	0.09
390.06	11.388	0.0423	0.00	0.13	584.47	0.0423	-0.01
390.04	11.092	0.0408	0.01	0.02	567.54	0.0410	-0.45
390.05	10.704	0.0393	0.01	0.16	543.14	0.0392	0.33
390.06	10.407	0.0379	0.00	0.13	522.94	0.0377	0.43
390.04	10.109	0.0359	0.00	0.06	501.63	0.0363	-1.08
390.07	9.810	0.0341	0.00	0.18	478.60	0.0348	-2.02
390.05	9.508	0.0324	0.00	0.20	454.73	0.0333	-2.52
390.06	9.307	0.0312	0.00	0.01	438.22	0.0323	-3.32
390.05	9.026	0.0299	0.01	0.10	414.98	0.0310	-3.42
390.04	8.760	0.0286	0.00	0.23	392.87	0.0298	-3.91
390.06	8.497	0.0275	0.00	0.24	370.97	0.0287	-3.98
390.04	8.209	0.0264	0.01	0.15	347.75	0.0275	-4.01
390.05	7.621	0.0244	0.01	0.07	302.61	0.0255	-4.55
390.06	7.316	0.0234	0.02	0.18	280.87	0.0246	-5.08
390.06	6.966	0.0227	0.00	0.16	257.51	0.0237	-4.36
390.05	6.965	0.0226	0.01	0.20	257.47	0.0237	-4.78
390.05	6.644	0.0218	0.01	0.19	237.46	0.0230	-5.20
390.06	6.222	0.0209	0.00	0.16	213.09	0.0222	-5.64
390.06	5.810	0.0204	0.01	0.12	191.28	0.0215	-4.91
390.06	5.345	0.0199	0.02	0.19	168.74	0.0208	-4.73
390.05	4.845	0.0193	0.03	0.73	146.63	0.0202	-4.86
390.06	4.319	0.0191	0.09	0.35	125.38	0.0197	-3.28
390.06	3.757	0.0184	0.03	0.13	104.64	0.0189	-2.87
390.07	3.195	0.0181	0.14	1.66	85.62	0.0186	-2.75
390.07	2.449	0.0173	0.04	0.14	62.58	0.0182	-4.60
390.06	1.850	0.0170	0.00	0.11	45.63	0.0179	-4.91
390.06	0.923	0.0167	0.01	0.05	21.64	0.0176	-4.82
390.07	0.458	0.0168	0.00	0.14	10.48	0.0174	-3.53

Table 13. Experimental viscosities of the mixture R410A (continued).

T (K)	P (MPa)	η (mPa·s)	s_p/P (%)	s_η/η (%)	ρ_{calc} (kg/m ³)	η_{calc} (mPa·s)	$\Delta\eta$ (%)
360.70	64.452	0.1615	0.01	0.30	1157.80	0.1708	-5.41
360.69	57.805	0.1538	0.01	0.17	1138.15	0.1600	-3.90
360.69	51.370	0.1451	0.01	0.20	1116.95	0.1494	-2.87
360.70	44.930	0.1355	0.00	0.43	1093.00	0.1385	-2.14
360.71	39.975	0.1286	0.00	0.22	1072.14	0.1298	-0.93
360.69	35.472	0.1215	0.01	0.31	1050.88	0.1217	-0.19
360.71	31.282	0.1145	0.01	0.35	1028.32	0.1065	7.57
360.71	27.730	0.1090	0.01	0.20	1006.56	0.1012	7.77
360.71	24.575	0.1026	0.02	0.13	984.47	0.0962	6.74
360.70	21.881	0.0972	0.01	0.07	962.88	0.0916	6.07
360.71	19.499	0.0922	0.01	0.20	940.82	0.0872	5.65
360.68	17.542	0.0878	0.01	0.16	920.05	0.0834	5.27
360.69	15.641	0.0829	0.02	0.13	896.33	0.0792	4.57
360.69	14.110	0.0780	0.01	0.46	873.81	0.0756	3.17
360.70	12.857	0.0745	0.01	0.34	852.01	0.0722	3.11
360.71	11.747	0.0705	0.02	0.22	829.04	0.0689	2.30
360.70	10.811	0.0667	0.01	0.17	805.90	0.0658	1.45
360.71	10.003	0.0627	0.03	0.31	781.48	0.0626	0.20
360.69	9.338	0.0599	0.01	0.25	757.12	0.0597	0.37
360.70	8.858	0.0573	0.02	0.19	735.50	0.0572	0.25
360.70	8.857	0.0573	0.00	0.08	735.45	0.0572	0.27
360.71	8.483	0.0550	0.01	0.06	715.33	0.0550	-0.01
360.71	8.020	0.0507	0.01	0.10	684.71	0.0518	-2.09
360.70	7.735	0.0492	0.01	0.08	661.19	0.0495	-0.53
360.69	7.545	0.0464	0.00	0.13	642.55	0.0477	-2.77
360.71	7.357	0.0442	0.00	0.16	620.22	0.0457	-3.34
360.69	7.162	0.0418	0.01	0.23	593.08	0.0433	-3.52
360.70	7.027	0.0394	0.00	0.26	569.93	0.0414	-4.83
360.70	6.804	0.0358	0.00	0.23	523.24	0.0378	-5.21
360.69	6.604	0.0324	0.00	0.52	472.60	0.0342	-5.10
360.69	6.403	0.0291	0.00	0.16	418.94	0.0307	-5.29
360.71	6.185	0.0261	0.00	0.19	366.42	0.0278	-5.95
360.71	6.181	0.0260	0.01	0.18	365.56	0.0277	-6.20
360.70	5.375	0.0206	0.01	0.21	242.77	0.0222	-7.27
360.71	5.145	0.0199	0.02	0.51	219.90	0.0214	-6.85
360.71	4.840	0.0192	0.04	0.17	194.13	0.0205	-6.24
360.70	4.581	0.0189	0.04	0.63	175.26	0.0199	-5.40
360.69	4.232	0.0182	0.03	0.44	153.01	0.0193	-5.80
360.71	3.769	0.0176	0.01	0.25	127.63	0.0186	-5.61
360.70	3.464	0.0176	0.05	0.21	112.91	0.0182	-3.72
360.70	2.976	0.0173	0.04	0.81	91.79	0.0178	-2.77
360.71	2.446	0.0171	0.19	0.40	71.53	0.0171	-0.25
360.71	1.836	0.0166	0.00	0.29	50.84	0.0168	-0.74
360.70	1.102	0.0161	0.01	0.17	28.79	0.0164	-1.86
360.70	0.299	0.0166	0.01	0.14	7.38	0.0161	2.88
360.71	0.149	0.0165	0.01	0.14	3.64	0.0161	2.54

Table 14. Saturated-liquid viscosities the for mixture R410A (0.5 R32 + 0.5 R125 by mass) measured in the sealed gravitational capillary viscometer. (Data reported in order of measurement.)

T (K) measured	ρ_{liq} (kg/m ³) calculated	ρ_{vap} (kg/m ³) calculated	η_{liq} (mPa·s) measured	η_{liq} (mPa·s) calculated	$\Delta\eta$ (%)
287.99	1107.6	47.85	0.1389	0.1393	-0.28
287.98	1107.7	47.84	0.1373	0.1393	-1.44
287.98	1107.7	47.84	0.1387	0.1393	-0.44
287.98	1107.7	47.84	0.1381	0.1393	-0.87
242.38	1282.6	10.03	0.2440	0.2667	-8.53
242.38	1282.6	10.03	0.2437	0.2667	-8.64
242.38	1282.6	10.03	0.2415	0.2667	-9.46
242.38	1282.6	10.03	0.2440	0.2667	-8.53
245.00	1273.7	11.12	0.2338	0.2560	-8.67
245.06	1273.5	11.15	0.2357	0.2557	-7.84
245.03	1273.6	11.14	0.2350	0.2559	-8.16
245.01	1273.7	11.13	0.2361	0.2559	-7.76
250.07	1256.2	13.50	0.2218	0.2368	-6.34
250.00	1256.5	13.46	0.2211	0.2371	-6.74
250.09	1256.1	13.51	0.2214	0.2368	-6.48
250.01	1256.4	13.47	0.2216	0.2370	-6.51
255.09	1238.5	16.23	0.2067	0.2197	-5.93
255.12	1238.4	16.25	0.2073	0.2196	-5.62
255.08	1238.5	16.23	0.2068	0.2198	-5.90
255.10	1238.5	16.24	0.2073	0.2197	-5.65
260.08	1220.4	19.38	0.1952	0.2044	-4.48
260.08	1220.4	19.38	0.1953	0.2044	-4.43
260.08	1220.4	19.38	0.1951	0.2044	-4.53
260.08	1220.4	19.38	0.1965	0.2044	-3.85
265.16	1201.5	23.08	0.1825	0.1901	-4.02
265.15	1201.5	23.07	0.1837	0.1902	-3.40
265.16	1201.5	23.08	0.1823	0.1901	-4.12
265.15	1201.5	23.07	0.1825	0.1902	-4.03
270.08	1182.6	27.19	0.1712	0.1775	-3.57
270.08	1182.6	27.19	0.1720	0.1775	-3.12
270.08	1182.6	27.19	0.1718	0.1775	-3.24
270.08	1182.6	27.19	0.1720	0.1775	-3.12
275.08	1162.7	31.98	0.1622	0.1658	-2.16
275.08	1162.7	31.98	0.1621	0.1658	-2.22
275.07	1162.7	31.97	0.1621	0.1658	-2.24
275.07	1162.7	31.97	0.1625	0.1658	-2.00
280.04	1142.2	37.43	0.1525	0.1550	-1.62
280.03	1142.3	37.41	0.1531	0.1550	-1.24
280.04	1142.2	37.43	0.1523	0.1550	-1.75
280.03	1142.3	37.41	0.1530	0.1550	-1.31
285.13	1120.4	43.84	0.1444	0.1447	-0.24
285.11	1120.4	43.81	0.1437	0.1448	-0.75
285.12	1120.4	43.82	0.1437	0.1448	-0.74
285.12	1120.4	43.82	0.1435	0.1448	-0.87

Table 14. Saturated-liquid viscosities for R410A (continued).

T (K)	ρ_{liq} (kg/m ³)	ρ_{vap} (kg/m ³)	η_{liq} (mPa·s)	η_{liq} (mPa·s)	$\Delta\eta$ (%)
measured	calculated	calculated	measured	calculated	
288.06	1107.3	47.95	0.1428	0.1392	2.62
288.06	1107.3	47.95	0.1387	0.1392	-0.33
288.06	1107.3	47.95	0.1388	0.1392	-0.26
288.06	1107.3	47.95	0.1382	0.1392	-0.69
290.11	1098.0	51.04	0.1356	0.1354	0.17
290.10	1098.0	51.02	0.1349	0.1354	-0.36
290.11	1098.0	51.04	0.1351	0.1354	-0.20
290.10	1098.0	51.02	0.1350	0.1354	-0.29
295.13	1074.3	59.39	0.1269	0.1265	0.31
295.14	1074.2	59.41	0.1270	0.1265	0.41
295.13	1074.3	59.39	0.1267	0.1265	0.16
295.13	1074.3	59.39	0.1260	0.1265	-0.40
300.13	1049.3	68.98	0.1193	0.1182	0.97
300.13	1049.3	68.98	0.1194	0.1182	1.05
300.13	1049.3	68.98	0.1192	0.1182	0.88
300.13	1049.3	68.98	0.1192	0.1182	0.88
305.06	1023.2	79.94	0.1112	0.1103	0.80
305.06	1023.2	79.94	0.1115	0.1103	1.07
305.05	1023.3	79.91	0.1114	0.1103	0.96
305.06	1023.2	79.94	0.1116	0.1103	1.16
310.08	994.8	92.95	0.1030	0.1027	0.32
310.08	994.8	92.95	0.1032	0.1027	0.51
310.07	994.8	92.92	0.1032	0.1027	0.50
310.08	994.8	92.95	0.1034	0.1027	0.70
315.18	963.5	108.58	0.0958	0.0952	0.63
315.18	963.5	108.58	0.0960	0.0952	0.84
315.17	963.5	108.55	0.0957	0.0952	0.50
315.17	963.5	108.55	0.0953	0.0952	0.09
320.07	930.5	126.53	0.0884	0.0881	0.31
320.08	930.4	126.57	0.0882	0.0881	0.15
320.08	930.4	126.57	0.0880	0.0881	-0.14
320.09	930.3	126.61	0.0883	0.0881	0.20
288.05	1107.4	47.94	0.1390	0.1392	-0.13
288.02	1107.5	47.90	0.1384	0.1392	-0.60
288.04	1107.4	47.92	0.1388	0.1392	-0.28
288.04	1107.4	47.92	0.1383	0.1392	-0.64

8. CONCLUSIONS

Measurements of thermophysical properties have been carried out to address some of the key data gaps for the properties of concern *vis a vis* the performance of blends operating at extreme conditions. These data have been used to develop new models for the thermodynamic properties for R125 and blends of the HFCs. The new equation of state for R125 is believed to be the most accurate and comprehensive formulation of the properties for 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 are being 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 two HFC blends were completed. 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.

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