

Pseudo-Pure Fluid Equations of State for the Refrigerant Blends R-410A, R-404A, R-507A, and R-407C

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Received February 13, 2003

Pseudo-pure fluid equations of state explicit in Helmholtz energy have been developed to permit rapid calculation of the thermodynamic properties of the refrigerant blends R-410A, R-404A, R-507A, and R-407C. The equations were fitted to values calculated from a mixture model developed in previous work for mixtures of R-32, R-125, R-134a, and R-143a. The equations may be used to calculate the single-phase thermodynamic properties of the blends; dew and bubble point properties are calculated with the aid of additional ancillary equations for the saturation pressures. Differences between calculations from the pseudo-pure fluid equations and the full mixture model are on average 0.01%, with all calculations less than 0.1% in density except in the critical region. For the heat capacity and speed of sound, differences are on average 0.1% with maximum differences of 0.5%. Generally, these differences are consistent with the accuracy of available experimental data for the mixtures, and comparisons are given to selected experimental values to verify accuracy estimates. The equations are valid from 200 to 450 K and can be extrapolated to higher temperatures. Computations from the new equations are up to 100 times faster for phase equilibria at a given temperature and 5 times faster for single-phase state points given input conditions of temperature and pressure.

KEY WORDS: density; equation of state; heat capacity; HFC-32; HFC-125; HFC-134a; HFC-143a; R-404A; R-407C; R-410A; R-507A; refrigerant mixtures; speed of sound; thermodynamic properties; VLE.

1. INTRODUCTION

Calculation of phase equilibria from mixture models requires some of the most computationally intensive algorithms in the thermodynamic part of

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design and analysis of refrigerant systems. In order to increase the speed of calculations and to improve convergence of algorithms in the critical region, pseudo-pure fluid equations of state were developed to calculate the thermodynamic properties of the refrigerant blends R-410A (50% R-32, 50% R-125), R-404A (44% R-125, 4% R-134a, 52% R-143a), R-507A (50% R-125, 50% R-143a), and R-407C (23% R-32, 25% R-125, 52% R-134a), where the percentages are given on a mass basis (see Table I). R-507A is an azeotropic mixture of R-125 and R-143a. The equations were developed by fitting calculated values from a mixture model developed in previous work (Lemmon and Jacobsen [1]). The term "pseudo-pure" is used to emphasize that the new equations are similar in form to that of pure fluids, but that their use is intended for a specified blend of two or more components at a specified composition. Although the equations can calculate all thermodynamic properties of states in the single phase and along the saturation boundaries, they cannot be used to determine the composition of the phase in equilibrium with a saturated state. The full mixture model is required to obtain this information. (Three of the blends considered here are azeotropic or nearly azeotropic, so differences in the coexisting liquid and vapor compositions are small.)

The speed of calculations with the new equations is greatly enhanced by several factors. First, the smaller number of required terms means an increase in speed from 2 to 5 times over that of the mixture model. For saturation states, the time required to calculate bubble or dew point pressures is nearly negligible compared to the time that would be required for a

Table I. Refrigerant Blends Studied in this Work

Blend	Composition (mass percent)			
	R-32	R-125	R-134a	R-143a
R-410A	50	50		
R-404A		44	4	52
R-507A		50		50
R-407C	23	25	52	
Blend	Composition (mole percent)			
	R-32	R-125	R-134a	R-143a
R-410A	0.697 615	0.302 385		
R-404A		0.357 817	0.038 264	0.603 919
R-507A		0.411 840		0.588 160
R-407C	0.381 109	0.179 559	0.439 332	

full saturation calculation from the mixture model, which must find an equilibrium point with equal temperature, pressure, and fugacity of the different phases and components. Typical comparisons will be given later.

2. FITTING PROCEDURES

Values used for fitting in this work were calculated from the mixture model of Lemmon and Jacobsen [1] for mixtures of the refrigerants R-32, R-125, R-134a, and R-143a using nonlinear fitting techniques. This model was developed by considering all available experimental data over all compositions of the mixture constituents and has been extensively evaluated for the blends considered here. Calculated data between 200 and 400 K were used in fitting, and values between 150 and 1000 K were used to monitor the extrapolation behavior.

The initial equation for each blend used in the nonlinear fitting was constructed by combining the equations for the pure fluids and the equation for the mixture model, resulting in correlations with the number of terms ranging from 39 for R-507A to 74 for R-507C. Properties calculated from these original equations were identical to those from the mixture model. Terms were then deleted from the equations when they statistically contributed little to the calculated properties or were similar to other terms. After the deletion of a term or set of terms, the coefficients of the equation were refitted. In addition, the exponents on temperature were allowed to float, greatly increasing the capacity of the nonlinear fitter to derive a new equation that matched the mixture model, but with fewer terms. Comparisons were made after each fit to determine that the new equation agreed with calculated values from the mixture model within the desired tolerances. The one exception to the fitting procedure came in the development of the formulation for R-507A. In this case, the final equation for R-404A was used as an initial starting point for the equation for R-507A. The two blends are quite similar in composition, with each containing both R-125 and R-143a and with R-404A containing 4% of R-134a in addition to R-125 and R-143a.

The fitting of the calculated properties resulted in equations with 21 terms for two of the blends and 22 for the other two. The removal of further terms increased the overall deviations. The maximum allowable difference in density between calculated values from the new equation and those from the mixture model was 0.1%, except in the critical region. Likewise, deviations of heat capacities and speeds of sound were kept under 0.5%. The final equation for each blend was thus a composite of terms from the equations of state for the pure fluids and the mixture equation, with accuracies similar to those for the mixture model, but with substantially fewer terms.

3. PSEUDO-PURE FLUID EQUATIONS

The pseudo-pure fluid equations of state were formulated using the Helmholtz energy as the fundamental property with independent variables of density and temperature. This functional form has been routinely used for high-accuracy pure fluid equations of state,

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

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. The functional form used here is explicit in the dimensionless Helmholtz energy, α , using independent variables of dimensionless density and temperature,

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

where $\delta = \rho/\rho_m$, $\tau = T_m/T$, and ρ_m and T_m are reducing parameters for temperature and density. The reducing parameters for the two binary mixtures were defined to be the critical temperature (T_c) and density (ρ_c) of the refrigerant blends calculated from the mixture model. (The critical point of a mixture is defined as the point where $\partial^2 g/\partial x^2$ and $\partial^3 g/\partial x^3$ are simultaneously zero, where g is the Gibbs energy and x is the mole fraction of each component.) For the ternary mixtures, the reducing parameters were defined to be the properties at the maxcondentherm, the maximum in temperature along the dew-bubble curve. This state point (the maximum in temperature) for the two binary mixtures is nearly identical to the critical point due to the shapes of the dew and bubble curves. Similar reducing parameters were employed in the development of the pseudo-pure fluid equation for air (Lemmon et al. [2]). The reducing parameters for the refrigerant blends are given in Table II.

Table II. Reducing Parameters and Molar Mass

Blend	T_m (K)	p_m (MPa)	ρ_m (mol · dm ⁻³)	M (g · mol ⁻¹)
R-410A	344.494	4.9012	6.324	72.5854
R-404A	345.270	3.7348	4.940	97.6038
R-507A	343.765	3.7049	4.964	98.8592
R-407C	359.345	4.6317	5.260	86.2036

The ideal-gas Helmholtz energy is given in a dimensionless form by

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

where $\delta_0 = \rho_0 / \rho_m$, $\tau_0 = T_m / T_0$, and T_0 , ρ_0 , h_0^0 , and s_0^0 are used to define an arbitrary reference state point. The last part of this term, summed over the number of components m in the mixture, accounts for the entropy of mixing. The equations for the ideal-gas heat capacity were developed by fitting calculated values of c_p^0 from the mixture model for each refrigerant

Table III. Coefficients of the Ideal-Gas Equations

k	c_p^0		α^0	
	c_k	e_k	a_k	b_k
R-410A				
0	2.8749	0.1	36.8871	
1	2.0623	697.0	7.158 07	
2	5.9751	1723.0	-46.875 75	-0.1
3	1.5612	3875.0	2.0623	2.023 26
4			5.9751	5.001 54
5			1.5612	11.2484
R-404A				
0	1.2744	0.3	7.004 07	
1	0.630 78	413.0	7.986 95	
2	3.5979	804.0	-18.8664	-0.3
3	5.0335	1727.0	0.630 78	1.196 17
4			3.5979	2.328 61
5			5.0335	5.001 88
R-507A				
0	1.5680	0.25	9.935 41	
1	0.950 06	364.0	7.9985	
2	4.1887	815.0	-21.6054	-0.25
3	5.5184	1768.0	0.950 06	1.058 86
4			4.1887	2.370 81
5			5.5184	5.143 05
R-407C				
0	0.765 75	0.4	2.131 94	
1	1.4245	864.0	8.050 08	
2	3.9419	1887.0	-14.3914	-0.4
3	3.1209	4802.0	1.4245	2.404 37
4			3.9419	5.251 22
5			3.1209	13.3632

blend. Differences between the calculated values for the new equations and those from the mixture model are generally less than 0.02%. The equations are given by

$$\frac{c_p^0}{R} = c_0 T^{e_0} + c_1 \frac{u_1^2 \exp(u_1)}{[\exp(u_1) - 1]^2} + c_2 \frac{u_2^2 \exp(u_2)}{[\exp(u_2) - 1]^2} + c_3 \frac{u_3^2 \exp(u_3)}{[\exp(u_3) - 1]^2}, \quad (4)$$

where u_1 , u_2 , and u_3 are e_1/T , e_2/T , and e_3/T , respectively, and the molar gas constant, R , is $8.314472 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$. The equations represent the ideal-gas heat capacity for the mixture from 100 to 1000 K. The coefficients are given in Table III. A convenient form of the ideal-gas Helmholtz energy, derived from the integration of Eq. (4) and the application of a reference state with $h = 200 \text{ kJ} \cdot \text{kg}^{-1}$ and $s = 1 \text{ kJ} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ for the saturated liquid at 0°C , is

$$\begin{aligned} \alpha^0(\delta, \tau) = & \ln \delta - \ln \tau + a_0 + a_1 \tau + a_2 \tau^{b_2} \\ & + a_3 \ln[1 - \exp(-b_3 \tau)] + a_4 \ln[1 - \exp(-b_4 \tau)] \\ & + a_5 \ln[1 - \exp(-b_5 \tau)] \end{aligned} \quad (5)$$

where the coefficients and exponents are also given in Table III.

The functional form for the residual Helmholtz energy is

$$\alpha^r(\delta, \tau) = \sum_k N_k \delta^{i_k} \tau^{j_k} \exp(-\gamma_k \delta^{l_k}), \quad (6)$$

where γ_k is zero when l_k is zero and one when l_k is not zero. The coefficients and exponents for each blend are given in Table IV.

Equations (7) through (12) are used for calculating pressure (p), compressibility factor (Z), enthalpy (h), entropy (s), isochoric heat capacity (c_v), isobaric heat capacity (c_p), and the speed of sound (u). Equations for other properties such as energy and $dP/d\rho$ are given in Lemmon et al. [2] along with equations for the partial derivatives of α^r and α^0 . Table V gives calculated values for computer code verification.

$$Z = \frac{p}{\rho RT} = 1 + \delta \left(\frac{\partial \alpha^r}{\partial \delta} \right)_\tau \quad (7)$$

$$\frac{h}{RT} = \tau \left[\left(\frac{\partial \alpha^0}{\partial \tau} \right)_\delta + \left(\frac{\partial \alpha^r}{\partial \tau} \right)_\delta \right] + \delta \left(\frac{\partial \alpha^r}{\partial \delta} \right)_\tau + 1 \quad (8)$$

$$\frac{s}{R} = \tau \left[\left(\frac{\partial \alpha^0}{\partial \tau} \right)_\delta + \left(\frac{\partial \alpha^r}{\partial \tau} \right)_\delta \right] - \alpha^0 - \alpha^r \quad (9)$$

Table IV. Coefficients and Exponents of the Pseudo-Pure Fluid Equations

k	N_k	j_k	i_k	l_k	N_k	j_k	i_k	l_k	
R-410A					R-407C				
1	0.987 252	0.44	1	0	1.058 80	0.241	1	0	
2	-1.030 17	1.2	1	0	-1.120 18	0.69	1	0	
3	1.176 66	2.97	1	0	0.629 064	2.58	1	0	
4	-0.138 991	2.95	2	0	-0.351 953	1.15	2	0	
5	0.003 023 73	0.2	5	0	0.004 559 78	0.248	5	0	
6	-2.536 39	1.93	1	1	-1.757 25	2.15	1	1	
7	-1.966 80	1.78	2	1	-1.120 09	2.43	2	1	
8	-0.830 480	3.0	3	1	0.027 7353	5.3	2	1	
9	0.172 477	0.2	5	1	0.898 881	0.76	3	1	
10	-0.261 116	0.74	5	1	-1.175 91	1.48	3	1	
11	-0.074 5473	3.0	5	1	0.081 8591	0.24	5	1	
12	0.679 757	2.1	1	2	-0.079 4097	2.86	5	1	
13	-0.652 431	4.3	1	2	-0.000 010 4047	8.0	5	1	
14	0.055 3849	0.25	4	2	0.233 779	3.3	1	2	
15	-0.071 0970	7.0	4	2	-0.291 790	4.7	1	2	
16	-0.000 875 332	4.7	9	2	0.015 4776	0.45	4	2	
17	0.020 0760	13.0	2	3	-0.031 4579	8.4	4	2	
18	-0.013 9761	16.0	2	3	-0.004 425 52	16.2	2	3	
19	-0.018 5110	25.0	4	3	-0.010 1254	26.0	4	3	
20	0.017 1939	17.0	5	3	0.009 159 53	16.0	5	3	
21	-0.004 820 49	7.4	6	3	-0.003 615 75	8.7	6	3	
R-404A					R-507A				
1	6.109 84	0.67	1	0	6.249 82	0.692	1	0	
2	-7.794 53	0.91	1	0	-8.078 55	0.943	1	0	
3	0.018 3377	5.96	1	0	0.026 4843	5.8	1	0	
4	0.262 270	0.7	2	0	0.286 215	0.77	2	0	
5	-0.003 516 88	6.0	2	0	-0.005 070 76	5.84	2	0	
6	0.011 6181	0.3	4	0	0.010 9552	0.24	4	0	
7	0.001 059 92	0.7	6	0	0.001 161 24	0.69	6	0	
8	0.850 922	1.7	1	1	1.384 69	2.0	1	1	
9	-0.520 084	3.3	1	1	-0.922 473	3.0	1	1	
10	-0.046 4225	7.0	1	1	-0.050 3562	7.0	1	1	
11	0.621 190	2.05	2	1	0.822 098	2.2	2	1	
12	-0.195 505	4.3	2	1	-0.277 727	4.3	2	1	
13	0.336 159	2.7	3	1	0.358 172	2.7	3	1	
14	-0.037 6062	1.8	4	1	-0.012 6426	1.2	4	1	
15	-0.006 365 79	1.25	7	1	-0.006 070 10	1.23	7	1	
16	-0.075 8262	12.0	2	2	-0.081 5653	12.0	2	2	
17	-0.022 1041	6.0	3	2	-0.023 3323	6.0	3	2	
18	0.031 0441	8.7	4	2	0.035 2952	8.5	4	2	
19	0.013 2798	11.6	4	2	0.015 9566	11.5	4	2	
20	0.068 9437	13.0	2	3	0.075 5927	13.0	2	3	
21	-0.050 7525	17.0	3	3	-0.054 2007	17.0	3	3	
22	0.016 1382	16.0	5	3	0.017 0451	16.2	5	3	

Table V. Calculated Values for Computer Code Verification

Blend	Temp. (K)	Pressure (MPa)	Density (mol · dm ⁻³)	Isochoric Heat Capacity (J · mol ⁻¹ · K ⁻¹)	Isobaric Heat Capacity (J · mol ⁻¹ · K ⁻¹)	Speed of Sound (m · s ⁻¹)
R-410A	300	0.0	0.0	50.400	58.714	200.08
^a	300	1.7404	14.45917	67.147	125.50	418.60
^b	300	1.7351	0.95997	67.335	107.60	160.94
	250	17.651	18.0	62.521	98.401	800.83
R-404A	300	0.0	0.0	76.219	84.533	168.36
^a	300	1.3169	10.60497	90.653	152.11	365.11
^b	300	1.3034	0.70599	87.917	121.86	132.92
	250	10.435	13.0	83.062	123.27	688.27
R-507A	300	0.0	0.0	76.838	85.152	167.22
^a	300	1.3462	10.50670	91.290	153.79	356.72
^b	300	1.3450	0.73552	88.742	124.15	130.95
	250	12.916	13.0	83.541	123.21	697.89
R-407C	300	0.0	0.0	62.631	70.945	181.04
^a	300	1.2507	13.10230	78.624	133.31	458.46
^b	300	1.0757	0.53670	74.027	99.203	154.41
	250	25.372	16.0	74.065	110.74	851.38

^a Bubble point.^b Dew point.

$$\frac{c_v}{R} = -\tau^2 \left[\left(\frac{\partial^2 \alpha^0}{\partial \tau^2} \right)_\delta + \left(\frac{\partial^2 \alpha^r}{\partial \tau^2} \right)_\delta \right] \quad (10)$$

$$\frac{c_p}{R} = \frac{c_v}{R} + \frac{\left[1 + \delta \left(\frac{\partial \alpha^r}{\partial \delta} \right)_\tau - \delta \tau \left(\frac{\partial^2 \alpha^r}{\partial \delta \partial \tau} \right) \right]^2}{\left[1 + 2\delta \left(\frac{\partial \alpha^r}{\partial \delta} \right)_\tau + \delta^2 \left(\frac{\partial^2 \alpha^r}{\partial \delta^2} \right)_\tau \right]} \quad (11)$$

$$\frac{u^2 M}{RT} = \frac{c_p}{c_v} \left[1 + 2\delta \left(\frac{\partial \alpha^r}{\partial \delta} \right)_\tau + \delta^2 \left(\frac{\partial^2 \alpha^r}{\partial \delta^2} \right)_\tau \right] \quad (12)$$

4. VAPOR-LIQUID EQUILIBRIA (VLE) PROPERTIES

Calculations of vapor-liquid equilibria properties from the mixture model require properties for states at compositions other than those of the specified blends. Since the equations given here do not account for composition, ancillary equations for the bubble and dew point pressures are required to calculate VLE properties. Once a saturated pressure has been calculated for a mixture state, the density of the saturated liquid or vapor can be determined by iterative techniques applied to the equation of state

for the pseudo-pure fluid. Additional thermodynamic properties are then calculated given the temperature and density of the state point for either phase.

The dew and bubble point pressures of the refrigerant blends are obtained with the ancillary equation

$$\ln\left(\frac{p_\sigma}{p_m}\right) = \frac{T_m}{T} \sum_{k=1}^4 N_k \theta^{t_k}, \quad (13)$$

where $\theta = 1 - T/T_m$, p_m and T_m are the reducing parameters given in Table II and p_σ represents either the dew or the bubble point pressure (as shown in Figs. 1 and 2 for R-407C and R-404A, respectively). The coefficients and exponents for Eq. (13) are given in Table VI. Calculations from the ancillary equations result in values that agree with the mixture model within 0.02%, except for a few cases that reach up to 0.05% near the reducing point. Although the use of the exponent t_k with values less than one violates the conditions outlined by Lemmon and Goodwin [3] for pure-fluid vapor-pressure equations, it plays an important role in mixture situations. Its use causes the slope of the ancillary equation to increase or

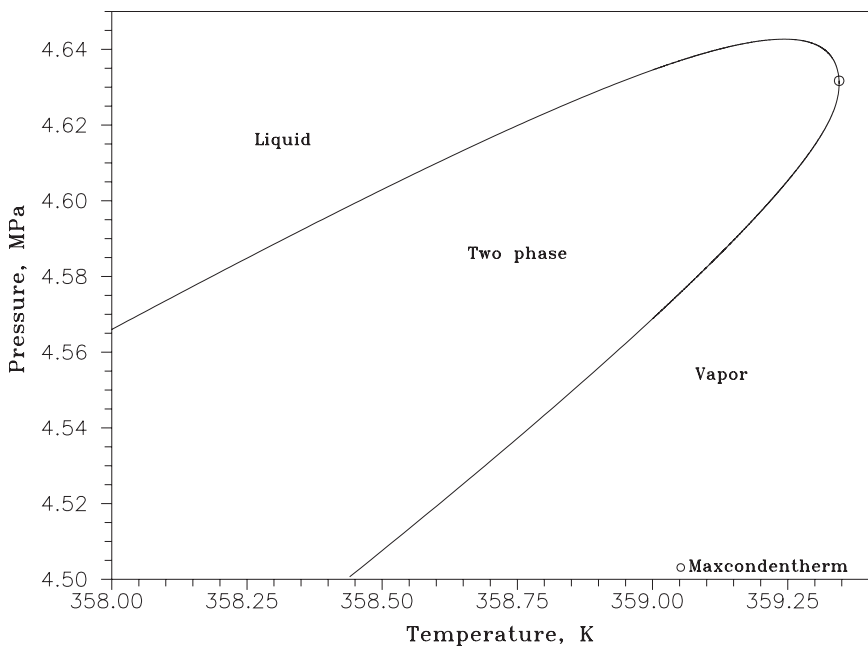


Fig. 1. Bubble and dew point curves of R-407C calculated from the ancillary equations in the vicinity of the critical point.

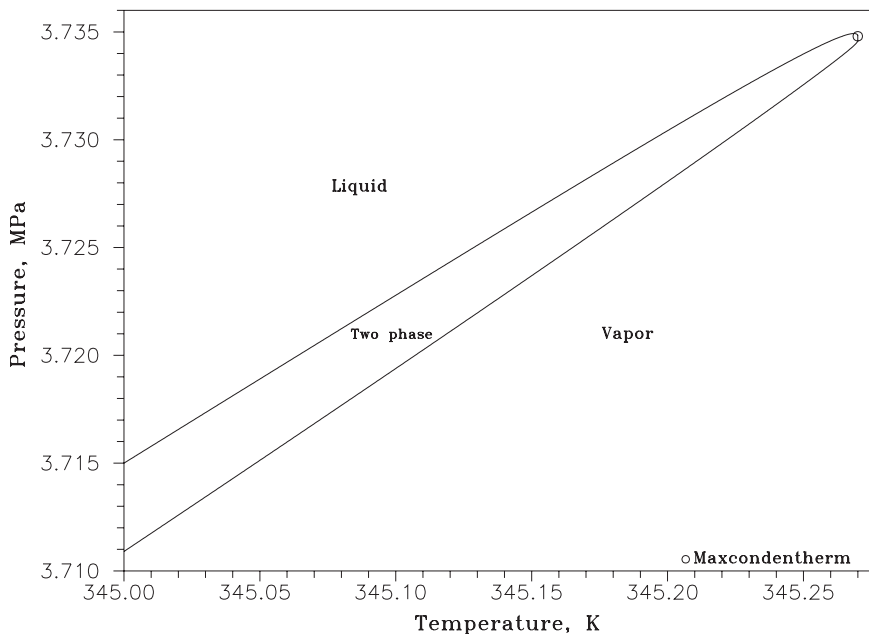


Fig. 2. Bubble and dew point curves of R-404A calculated from the ancillary equations in the vicinity of the critical point.

decrease rapidly as the reducing point is approached, making possible the construction of typical dew-bubble curves for mixtures, as shown in Figs. 1 and 2. The dew and bubble curves for R-410A are nearly coincident and follow the behavior of a typical pure fluid. Although the composition of R-410A is not at an azeotropic point for mixtures of R-32 and R-125, the compositional change over the phase boundaries is very small. For R-410A and the azeotropic blend R-507A, exponents with values less than one were not used.

5. COMPARISONS TO DATA AND TO THE MIXTURE MODEL

Comparisons were made to calculations between the pseudo-pure fluid equations and the mixture model to ensure that densities over the whole thermodynamic surface between 200 and 450 K with pressures up to 50 MPa were within 0.1% except in the immediate region of the critical point. Within this limited region, comparisons were made to ensure that pressures (calculated from density and temperature) were within 0.1%. These deviations are consistent with the most reliable experimental data for the mixtures. Approximately 2000 data points spread evenly over the fluid

Table VI. Coefficients and Exponents of the Bubble- and Dew-Point Pressure Equations

k	Bubble Point			Dew Point	
	N_k	t_k		N_k	t_k
			R-410A		
1	-7.2818	1.0		-7.4411	1.0
2	2.5093	1.8		1.9883	1.6
3	-3.2695	2.4		-2.4925	2.4
4	-2.8022	4.9		-3.2633	5.0
			R-404A		
1	0.061 067	0.54		-0.000 268 63	0.1
2	-6.5646	0.965		-6.5757	0.972
3	-3.6162	3.7		-4.1802	3.8
4	-3.9771	9.0		-7.9102	9.0
			R-507A		
1	-7.4853	1.0		-7.5459	1.0
2	2.0115	1.5		2.3380	1.5
3	-2.0141	2.2		-2.2370	2.1
4	-3.7763	4.6		-4.1535	4.7
			R-407C		
1	0.487 22	0.54		-0.086 077	0.4
2	-6.6959	0.925		-6.6364	0.965
3	-1.4165	2.7		-2.4648	3.1
4	-2.5109	4.7		-3.4776	5.0

surface were used as check points. On average, absolute differences between calculations from the pseudo-pure fluid equations and the full mixture model are 0.01% in density. Likewise, comparisons were made to check that calculated values of the isochoric heat capacity, isobaric heat capacity, and the speed of sound were all within 0.5% (except near the critical point, where a few of the deviations were slightly larger). Average deviations for these properties are 0.1%.

At temperatures above 450 K, deviations between the pseudo-pure fluid equations and the mixture model are similar to those described above, even up to 1000 K. However, the maximum limits for the pure fluid equations are around 450 K, and the effects of dissociation of the molecules increase as temperature approaches these maximum limits. At temperatures down to 150 K, the equations continue to show differences of less than 0.1% in density. However, differences in heat capacities tend to increase rapidly from 200 K down to 150 K, except for the equation for the R-410A blend.

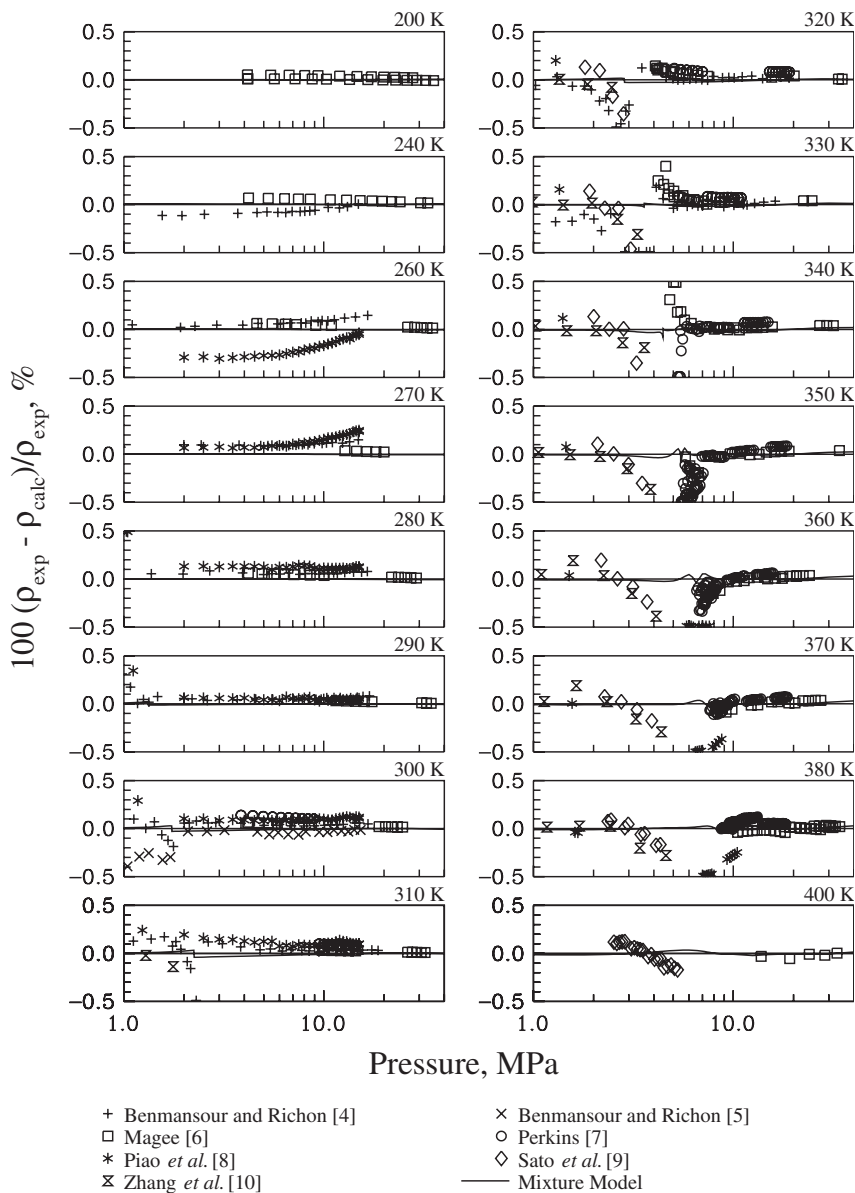


Fig. 3. Comparisons of densities calculated from the pseudo-pure fluid equation of state for R-410A to experimental data for the R-32/125 binary mixture at compositions near that of R-410A.

Experimental data are available to compare against all four blends, although data for the R-507A blend are very sparse, and comparisons with these data are not shown here. Figure 3 shows deviations between the R-410A pseudo-pure fluid equation and experimental data with compositions between 0.4982 and 0.5007 mass fraction of R-32. (Each small plot represents a 10 K temperature range commencing with the value listed above each plot.) Comparisons between the R-404A pseudo-pure fluid equation and experimental data are shown in Fig. 4. (The compositions of

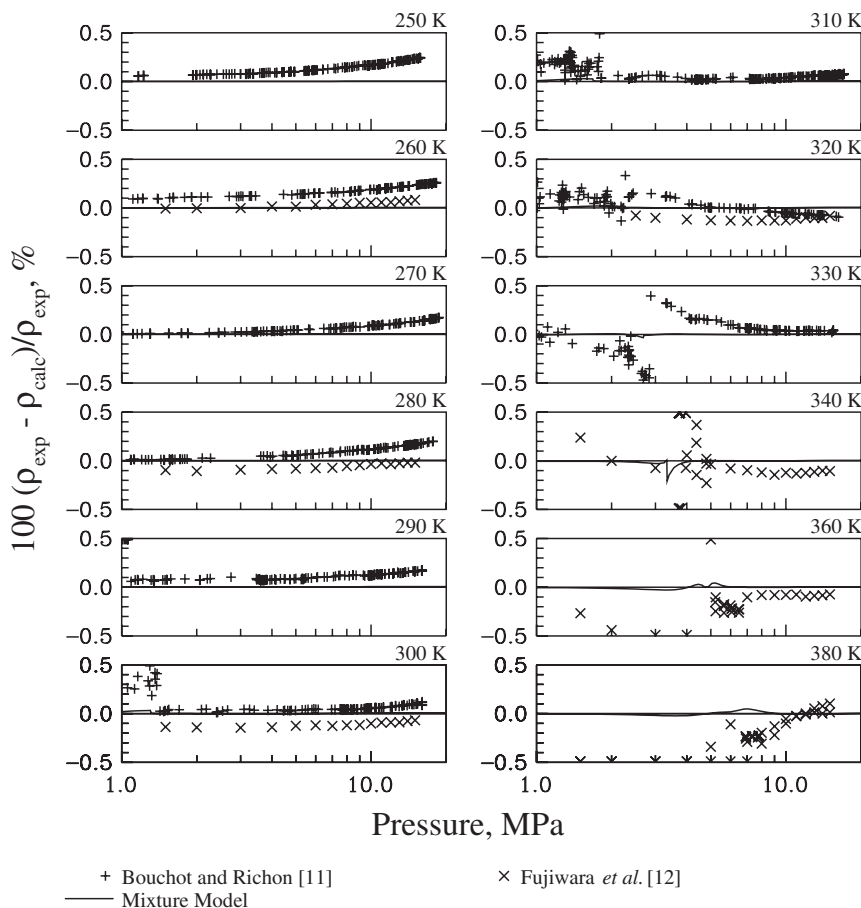


Fig. 4. Comparisons of densities calculated from the pseudo-pure fluid equation of state for R-404A to experimental data for the R-125/134a/143a ternary mixture at compositions near that of R-404A.

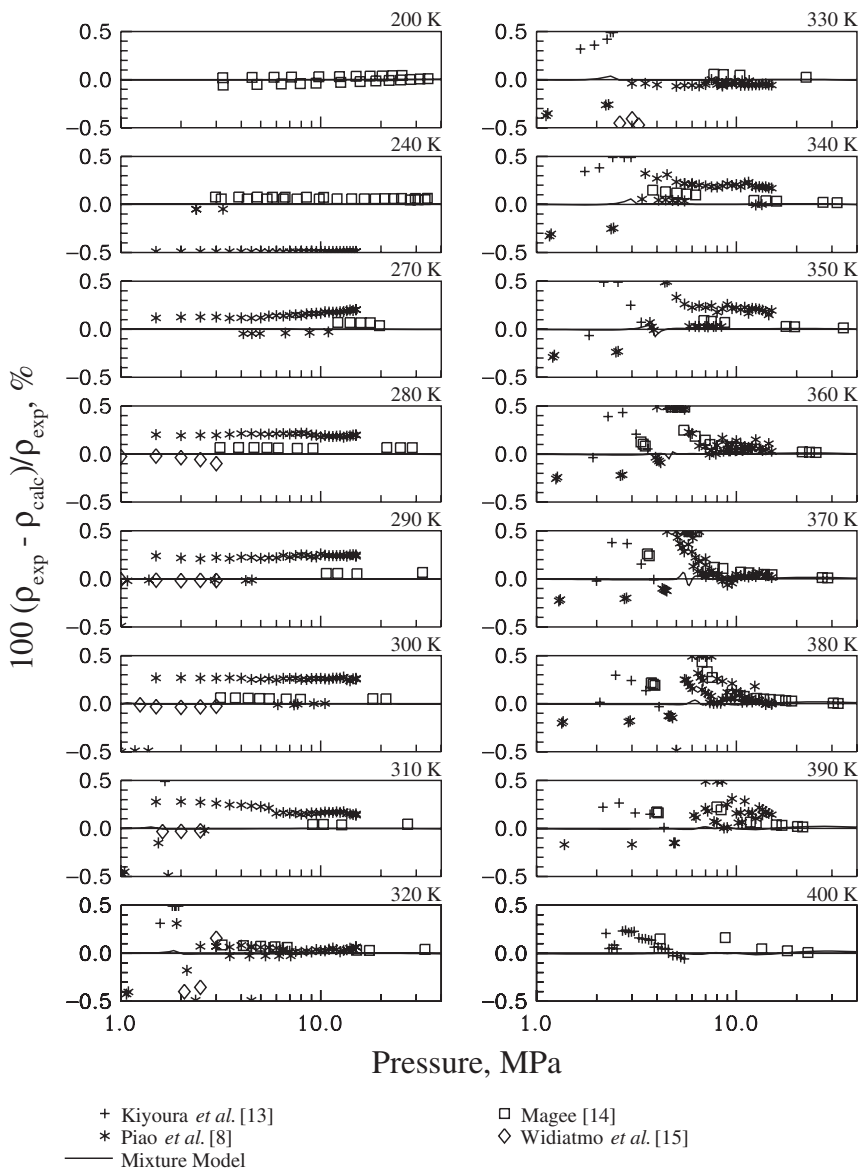


Fig. 5. Comparisons of densities calculated from the pseudo-pure fluid equation of state for R-407C to experimental data for the R-32/125/134a ternary mixture at compositions near that of R-407C.

the data are nearly identical with those given for R-404A in Table I). Similar deviations are shown in Fig. 5 comparing the R-407C pseudo-pure fluid equation and experimental data with compositions between 0.2290 and 0.2308 mass fraction of R-32 and 0.2493 and 0.2512 mass fraction of R-125. Comparisons of properties calculated using the pseudo-pure fluid equation with those from the mixture model are also shown in the figures, although, for the most part, the plots of the differences are indistinguishable from the zero deviation line. The comparisons of the full mixture model to all available data for mixtures of R-32, R-125, R-134a, and R-143a should be consulted for additional information on the quality of the data and of the fit of the mixture model to the available experimental data (Lemmon and Jacobsen [1]). The comparisons shown in Figs. 3–5 do not give a full overview of the quality of the pseudo-pure equations, since many of the high accuracy mixture data were measured at compositions other than those of the blends represented by the equations given here and are not shown in the figures.

6. CALCULATIONAL SPEED

The computation times required for various calculations were compared to determine the effectiveness of the new equations. The pseudo-pure fluid equation for R-407C was compared with the full mixture model at the composition given in Table I. The Fortran code from the REFPROP program (Lemmon et al. [16]) was used for all calculations. For saturation conditions given a specified bubble-point temperature, calculations between 200 to 350 K showed that the new equation was 85 times faster than the full mixture model. Over the same range of temperatures and at 1 MPa, calculations of single-phase state points with an unknown input phase (i.e., liquid or vapor) showed an increase in speed by a factor of 100. Likewise, conditions at 1 MPa over a range of enthalpies from 100 to 450 kJ·kg⁻¹ demonstrated that the pseudo-pure fluid equation was 40 times faster than the mixture model. In the special case where the input phase was known (thus, the calculation of the phase equilibria was not required), calculations from the new equation were 5 times faster than those for the mixture model, given input conditions of 1 MPa from 210 to 290 K (all state points were in the liquid).

ACKNOWLEDGMENTS

This work was funded by the Building Technologies Program of the U.S. Department of Energy, by the 21-CR research program of the Air-Conditioning and Refrigeration Technology Institute, and by the National

Institute of Standards and Technology. Many thanks are given to Mark McLinden of NIST, Boulder, for his assistance and suggestions during the development and documentation of the equations.

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