International Journal of Thermophysics, Vol. 20, No. 2, 1999

Viscosity of Gaseous HFC-143a (1,1,1-Trifluoroethane) Under High Pressures

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Received June 9, 1998

The viscosity of gaseous HFC-143a(1,1,1-trifluoroethane) was measured with an oscillating-disk viscometer of the Maxwell type at temperatures from 298.15 to 423.15 K and at pressures up to the saturated vapor pressure at each temperature under subcritical conditions or up to 9 MPa under supercritical conditions. Intermolecular potential parameters of HFC-143a for the extended corresponding states were determined from the viscosity data at 0.1 MPa. An empirical viscosity equation as functions of temperature and density is proposed to interpolate the present experimental results.

KEY WORDS: corresponding states; HFC-143a; viscosity.

1. INTRODUCTION

There has been a great interest in the thermophysical properties of HFC-143a (1,1,1-trifluoroethane), since it is considered to be an environmentally acceptable alternative for CFC-22 and CFC-502. Binary mixtures or ternary mixtures have also been recommended by the industry as potential alternatives. HFC-143a is one of the constituents in the mixture alternatives HFC-507 (49.91% HFC-143a + 50.09% HFC-125) and HFC-404A (52% HFC-143a + 44% HFC-125 + 4% HFC-134a).

Transport properties, such as viscosity and thermal conductivity, are essential in the analysis of mass and heat transfer processes in heat exchangers. Transport properties of the alternative refrigerants have a

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0195-928X/99/0300-0435$16.00/0

major impact on equipment design and thus influence the economical feasibility of heat exchangers which can actually approach the theoretical efficiency of the thermodynamic cycle with the ozone-depleting refrigerants.

In this paper, we present experimental results for the viscosity of gaseous HFC-143a under high pressures. The measurements were made at temperatures from 298.15 to 423.15 K and at pressures up to the saturated vapor pressure at each temperature under subcritical conditions or up to 9 MPa under supercritical conditions. The viscosity data at 0.1 MPa were applied to determine the scaling parameters of HFC-143a needed in the extended law of corresponding states. The data at high pressures were used to develop an empirical viscosity equation as functions of temperature and density.

The viscosity of HFC-143a in the liquid phase has been measured by few researchers [1–6]. The viscosity of HFC-143a in the gaseous phase at 298.15 K and at 0.1 MPa has been measured by Dunlop [7]. The gaseous viscosity of HFC-143a under high pressures, however, has not yet been measured.

2. EXPERIMENTS

The viscosity was measured with an oscillating-disk viscometer of the Maxwell type. The gas density at the experimental condition of the viscosity measurement was measured with a high-pressure gas pipette. The experimental apparatus and procedure were the same as those described in previous studies [8–11]. The apparatus constant at the experimental temperature and pressure conditions was determined by considering the viscosity data of nitrogen taken from Stephan et al. [12] and the nitrogen-gas density data from Jacobsen et al. [13]. Temperature and pressure values have an uncertainty of 0.01 K and 0.5 kPa. Density values have an uncertainty of $0.03\ \mathrm{kg \cdot m^{-3}}$. The estimated error in the measurements of viscosity is within 0.3%.

The sample was supplied by Asahi Glass Co.Ltd. The purity of the sample, certified by the suppliers, was approximately 99.9 mol%. The sample was purified by distillation several times.

3. RESULTS

The experimental results for viscosity and density are presented in Table I and shown in Figs. 1 and 2. From Fig. 2, it can be seen that a negative initial density slope was observed for the viscosity isotherm at 298.15 K.

Table I. Viscosity of HFC-143a

P (MPa)	ρ (kg · m^{-3})	η (μPa · s)
	$T = 298.15$ K	
0.1008	3.417	11.210
0.2138	7.248	11.199
0.3313	11.232	11.139
0.4482	16.433	11.119
0.5686	21.389	11.114
0.6866	26.446	11.110
0.8149	32.355	11.119
0.9223	37.623	11.146
1.0259	43.095	11.123
1.1361	49.822	11.153
	$T = 323.15$ K	
0.1012	3.206	12.244
0.2914	9.453	12.236
0.4853	16.208	12.248
0.6808	23.257	12.248
0.8798	31.094	12.324
1.0730	39.248	12.359
1.2675	48.151	12.483
1.4714	58.307	12.566
1.6622	68.964	12.634
1.8536	80.976	12.785
2.1295	101.99	13.171
2.2388	111.86	13.428
	$T = 348.15$ K	
0.1021	2.992	13.209
0.3480	10.438	13.202
0.5918	18.194	13.235
0.8370	26.433	13.295
1.0797	35.106	13.345
1.3288	44.616	13.455
1.5663	54.371	13.547
1.7947	64.478	13.673
2.1489	81.812	13.968
2.4058	96.077	14.231
2.6358	110.54	14.559
3.0052	138.62	14.998
3.1921	156.55	15.799
3.4006	180.76	16.518
3.5503	203.23	17.332
3.6761	227.32	18.310

Table I. *(Continued)*

P (MPa)	ρ ($\mathrm{kg \cdot m^{-3}}$)	η ($\mu\mathrm{Pa \cdot s}$)
	$T = 373.15$ K	
0.1024	2.792	14.109
0.3540	9.848	14.131
0.6500	18.494	14.249
0.9424	27.484	14.284
1.2369	37.031	14.332
1.5304	47.073	14.457
1.8252	57.874	14.618
2.1531	70.733	14.794
2.4257	82.174	14.920
2.7295	96.042	15.172
3.0476	111.84	15.532
3.4078	131.95	16.045
3.7359	152.60	16.630
4.0178	172.61	17.265
4.2694	192.44	17.956
4.4937	212.81	18.704
4.6911	232.75	19.488
4.8091	246.55	20.047
4.9729	266.33	20.902
5.1226	284.81	21.852
	$T = 398.15$ K	
0.1008	2.573	15.045
0.4013	10.433	15.094
0.7081	18.761	15.137
1.0483	28.394	15.249
1.4405	40.057	15.342
1.8319	52.419	15.516
2.2396	66.180	15.752
2.6129	79.464	15.975
3.0119	94.748	16.300
3.4817	114.30	16.765
3.9126	133.76	17.311
4.3645	156.32	17.987
4.7136	175.64	18.600
5.0323	194.06	19.224
5.3288	212.67	19.936
5.6721	235.79	20.879
5.9702	257.26	21.797
6.3416	285.09	23.106
6.6684	311.10	24.450
6.8054	326.46	25.246

Table I. *(Continued)*

P (MPa)	ρ (kg · m^{-3})	η (μPa · s)
	T = 423.15 K	
0.1035	2.484	16.050
0.4959	12.114	16.150
0.8847	22.081	16.222
1.3219	33.747	16.355
1.8270	47.916	16.547
2.3431	63.228	16.788
2.8014	77.748	17.098
3.3575	96.391	17.508
3.8601	114.35	17.937
4.4243	135.99	18.541
4.8321	152.56	19.093
5.2869	172.25	19.709
5.8436	197.32	20.655
6.3019	220.27	21.542
6.8185	246.94	22.664
7.3580	276.36	24.031
7.8603	302.04	25.431
8.4453	336.64	27.245
8.8523	362.21	28.550

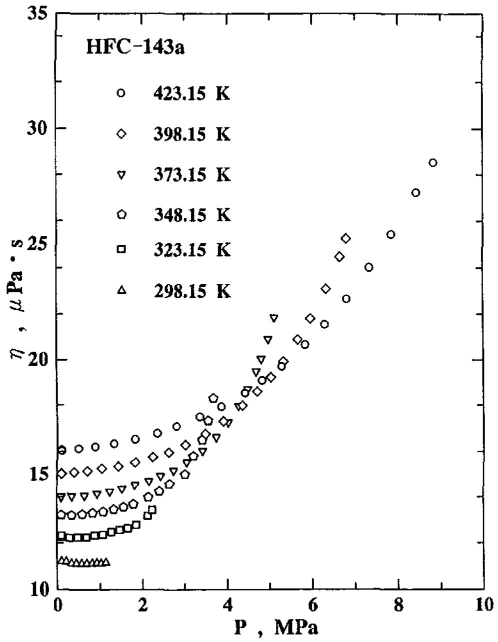

Fig. 1. Viscosity of HFC-143a as a function of pressure.

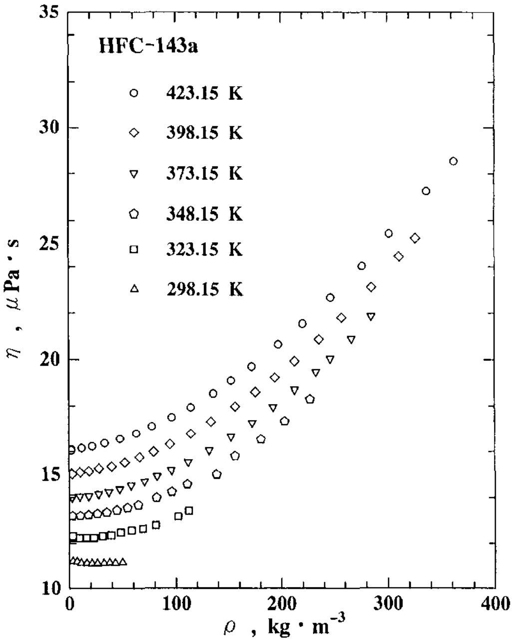

Fig. 2. Viscosity of HFC-143a as a function of density.

The low-pressure gas viscosity can be represented by the Chapman–Enskog equation derived from the kinetic theory for dilute gases:

$$\eta_0 = \frac{5}{16}\frac{(MkT)^{0.5}}{(\pi N)^{0.5}}\frac{f_\eta}{\sigma^2 \Omega^{(2,2)*}(T^*)} \tag{1}$$

In Eq. (1), k is Boltzmann's constant, M is the molar mass in kg · kmol^{-1}, N is Avogadro's number, $\Omega^{(2,2)*}(T^*)$ is the collision integral, f_η is the higher-order correction factor for viscosity, $T^* = kT/\varepsilon$ is the reduced temperature, T is the absolute temperature, η_0 is the gas viscosity at 0.1 MPa in μPa · s, and ε and σ are the characteristic scaling parameters. Based on accurate experimental data for the second virial coefficient and gaseous viscosity of noble gases, Kestin et al. [14–16] developed an extended corresponding states principle, which is a most powerful method to predict transport properties of pure gases and gaseous mixtures at normal pressure. As for the collision integral and correction factor, we have used the following equation presented by Kestin et al. [16]:

$$\Omega^{(2,2)*}(T^*) = \exp[0.46641 - 0.56991 \ln T^* + 0.19591(\ln T^*)^2 - 0.03879(\ln T^*)^3 + 0.00259(\ln T^*)^4] \tag{2}$$

Table II. Potential Parameters for HFC-143a and Deviation of Experimental Viscosity at 0.1 MPa from Eq. (1)[a]

ε/k	365.58 K
σ	0.4885 nm
Average deviation	0.19%
Maximum deviation	0.45%

[a] Average deviation = $100\,|\eta_{0,\mathrm{exp}} - \eta_{0,\mathrm{cal}}|/\eta_{0,\mathrm{cal}}/n$. Maximum deviation = max of $100\,|\eta_{0,\mathrm{exp}} - \eta_{0,\mathrm{cal}}|/\eta_{0,\mathrm{cal}}$. n = number of data.

and

$$f_\eta = 1 + 3(8E^* - 7)^2/196 \tag{3}$$

where E^* can be obtained from the following equation:

$$E^* = 1 + \frac{T^*}{4}\frac{d \ln \Omega^{(2,2)*}}{dT^*} \tag{4}$$

The values of the scaling parameters, σ and ε, can be determined from the gas viscosity data at 0.1 MPa. For the gas viscosity at 298.15 K and 0.1 MPa, the present result is about 1% lower than the viscosity value of Dunlop [7]. Therefore, we used the present results only for the determination of the scaling parameters. The optimum values of the parameters σ and ε and the deviations of the calculated values from Eq. (1) are given in Table II. The present viscosity data can be represented well by Eq. (1) with the values of the scaling parameters in Table II, with a maximum deviation of 0.45% and an average deviation of 0.19% (Fig. 3).

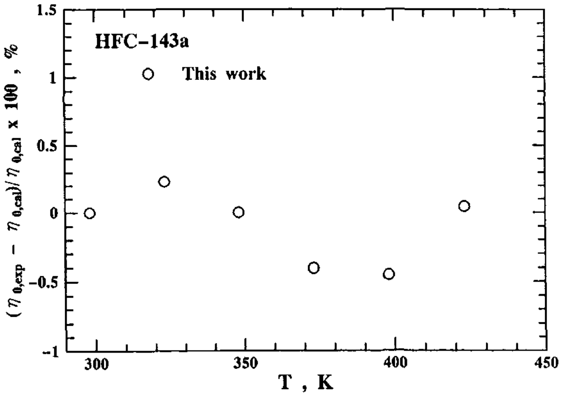

Fig. 3. Deviations of experimental viscosity values of HFC-143a at 0.1 MPa from those calculated with Eq. (1).

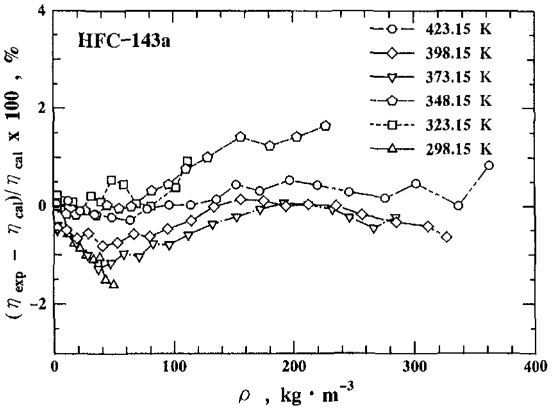

Fig. 4. Deviations of experimental viscosity values of HFC-143a at high pressures from those calculated with Eq. (5).

For the gas viscosity η at temperature T and at high pressures, we developed the following empirical viscosity equation as a function of temperature and density:

$$\eta = \eta_0 + a_0(\rho - \rho_0) + a_1(\rho - \rho_0)^2 \tag{5}$$

with

$$a_0 = -0.0254485 + 8.03031 \times 10^{-5} T \tag{6}$$

$$a_1 = 1.29211 \times 10^{-4} - 1.28578 \times 10^{-7} T \tag{7}$$

where η_0 is the gas viscosity at 0.1 MPa represented by Eq. (1), ρ is the gas density at high pressures in $\mathrm{kg \cdot m^{-3}}$, ρ_0 is the gas density at 0.1 MPa in $\mathrm{kg \cdot m^{-3}}$, and T is the absolute temperature in K. The values of the coefficients in Eqs. (6) and (7) were determined from a least-squares fit of Eq. (5) to the present experimental viscosity values. Figure 4 shows the deviations of the present results from Eq. (5). As can be seen from Fig. 4, Eq. (5) represents the present results with an average deviation of 0.49% and a maximum deviation of 1.6%. It should be noted that Eq. (5) should not be used outside the temperature and density ranges of this study.

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