International Journal of Thermophysics, Vol. 21, No. 3, 2000

Viscosity of Gaseous HCFC-123 (2,2-Dichloro-1,1,1-Trifluoroethane) in the Temperature Range from 323.15 to 423.15 K and at Pressures up to 2 MPa

C. Yokoyama[1, 2] **and M. Takahashi**[1]

Received July 13, 1999

The viscosity of gaseous HCFC-123 (2,2-dichloro-1,1,1-trifluoroethane) was measured with an oscillating-disk viscometer of the Maxwell type at temperatures from 323.15 to 423.15 K and at pressures up to the saturated vapor pressure at each temperature in subcritical conditions or up to 2 MPa under supercritical conditions.

KEY WORDS: HCFC-123; viscosity.

1. INTRODUCTION

Measurements of viscosities of gaseous halogenated hydrocarbons under pressure are being continued by the present authors [1, 2]. As part of a continuing study of the viscosity of new environmentally acceptable CFC alternative refrigerants, measurements of the viscosity of 2,2-dichloro-1,1,1-trifluoroethane (HCFC-123), made between 323.15 and 423.15 K at pressures up to 2 MPa, are reported in this study. HCFC-123 has been considered a promising substitute for trichloromethane (CFC-11).

In 1990, we first presented our experimental results for the gaseous viscosity of HCFC-123 at the 11th Japan Symposium on Thermophysical Properties held in Tokyo [3]. At that time, the viscosity data were correlated with an empirical equation as a function of temperature and pressure. Numerical values of the viscosity have not yet been reported. Later, Dowdell and Matthews [4] and Nabizadeh and Mayinger [5] measured the gaseous viscosity of HCFC-123. Tanaka and Sotani [6]

[1] Research Institute for Chemical Reaction Science, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan.
[2] To whom correspondence should be addressed.

0195-928X/00/0500-0695$18.00/0

compiled experimental data for transport properties and developed a viscosity equation applicable over a wide range of temperature and pressure for superheated HCFC-123 based on our data obtained by a private communication. As for the pressure–volume–temperature (PVT) relationships, many researchers have measured the PVT relationships of HCFC-123. Younglove and McLinden proposed the most reliable equation of state for HCFC-123 (YM-EOS) [7]. It was found that the our density data reported in Ref. 3 deviate from the calculated values from the YM-EOS with an average deviation of about 3.3% and a maximum deviation of 31%. On the other hand, the viscosity values at 0.1 MPa agreed very well with the literature values of Dowdell and Matthews [4] and Nabizadeh and Mayinger [5]. We have concluded that the reason for the inaccuracy of our previous density values comes from leaking either in a high pressure gas pipette or a toepler pump in the density measurement system. As the density values were needed to determine the viscosity values, we had to examine the effect of density on the viscosity determination and recalculate the viscosity with accurate density values. In this paper, we report newly determined gaseous viscosity of HCFC-123 from the gas density obtained from the YM-EOS and the data of oscillation periods and damping ratio measured previously [3].

2. EXPERIMENTAL

The viscosity was measured with an oscillating-disk viscometer of the Maxwell type. The gas densities at the temperature and pressure conditions of the viscosity measurements were obtained from the YM-EOS [7]. The experimental apparatus and procedure were the same as those described in previous studies [1, 2]. The viscosity was determined by Newell's theory [8] and was expressed by the following equation.

$$\eta = (2\pi\rho b^2/\beta^2)\, T_o \tag{1}$$

where η represents the viscosity, ρ the density. The quantity b is the harmonic mean of b_1 and b_2, and b_1 and b_2 are the distance between the oscillating disk and the upper or lower fixed disks, respectively. The quantity β is the dimensionless ratio of b and the boundary layer thickness δ, and T_o is the period of oscillation in vacuo. On the other hand, β^2 was determined from the measured values of the logarithmic decrement $\varDelta$ and period of oscillation T from the cubic equation,

$$\begin{aligned} C_N = \{[2I/(\pi\rho R^4)](\varDelta/\tau - \varDelta_0) + a\varDelta/\tau\}\, \beta^2 \\ + f\{(3\varDelta^2 - 1)/\tau^2\}\, \beta^4 + h\{\varDelta(\varDelta^2 - 1)/\tau^3\}\, \beta^6 \end{aligned} \tag{2}$$

where C_N is the edge-effect constant, I is a moment of inertia of the quartz wire of our suspension system, R is the radius of the oscillating disk, $\tau = T/T_0$, and $a = 2/3$, $f = 1/45$, and $h = 8/945$, if $b_1 = b_2$. The subscript 0 indicates the value measured in vacuo. In the experimental conditions of the suspension system of the viscometer, the contributions of the second and third terms compared to the first term on the right-hand side are usually less than 0.8% and 0.00001%, respectively. Furthermore, the following conditions are satisfied for each contribution in the first term on the right-hand side of Eq. (2) at the highest density and temperature conditions of this study:

$$(2I/\pi\rho R^4)(\Delta/\tau):(2I/\pi\rho R^4)\,\Delta_0:a\Delta/\tau \risingdotseq 1:0.008:0.000004$$

Under other conditions, the first term dominates even more strongly and the second and third term contributions become less important. Therefore, β^2 can be calculated in the first approximation by

$$\beta^2 = (C_N \pi R^4 \tau\rho)/(2I\Delta) \tag{3}$$

The difference between the exact values of β^2 as the solutions of Eq. (2) and those of Eq. (3) was less than 0.7%. From Eqs. (1) and (3), the effect of density on β^2 and the viscosity determination can be seen. Almost the same viscosity values can be obtained even from 100% different density values. From the data analysis, it was found that the viscosity values did not change due to the density variation. It should be noted that the viscosity values are very sensitive to the edge-effect constant C_N. The C_N at the experimental temperature and pressure conditions was determined by considering the viscosity data for nitrogen taken from Stephan et al. [9], and the nitrogen gas density data from Jacobsen and Stewart [10]. Temperature and pressure values have an uncertainty of ± 0.01 K and ± 0.5 kPa. The estimated uncertainty of the present viscosity data 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 further by distillation several times.

3. RESULTS

The experimental results for viscosity 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 isotherms at 323.15 and 348.15 K. This behavior has also been observed in our previous studies [11, 12] and in highly accurate experimental studies by Vogel et al.

Table I. Experimental Viscosity Values, Along with Density Values Calculated from the Equation of State of Younglove and McLinden [7] for HCFC-123

P (MPa)	ρ ($kg \cdot m^{-3}$)	η ($\mu Pa \cdot s$)
	$T = 323.15$ K	
0.1011	5.951	11.677
0.1439	8.599	11.674
0.1677	10.110	11.676
0.2065	12.632	11.636
	$T = 348.15$ K	
0.1020	5.536	12.557
0.1538	8.457	12.555
0.2049	11.424	12.545
0.2513	14.192	12.535
0.2998	17.189	12.502
0.3496	20.355	12.479
	$T = 373.15$ K	
0.1004	5.047	13.403
0.2060	10.584	13.397
0.3022	15.859	13.405
0.3980	21.357	13.343
0.4936	27.130	13.321
0.5875	33.109	13.347
0.6605	38.002	13.335
0.7419	43.761	13.343
	$T = 398.15$ K	
0.1011	4.744	14.226
0.2207	10.560	14.157
0.3398	16.593	14.144
0.4529	22.572	14.226
0.5725	29.193	14.137
0.7097	37.223	14.226
0.8414	45.442	14.265
0.9778	54.592	14.293
1.0815	62.075	14.342
1.1771	69.464	14.413
	$T = 423.15$ K	
0.1024	4.508	15.014
0.1979	8.821	14.993
0.3460	15.732	15.015

Table I. *(Continued)*

P (MPa)	ρ ($kg \cdot m^{-3}$)	η ($\mu Pa \cdot s$)
	$T = 423.15$ K	
0.4935	22.911	15.009
0.6364	30.181	15.093
0.7844	38.080	15.076
0.9314	46.350	15.141
1.0731	54.781	15.195
1.2249	64.401	15.255
1.3708	74.331	15.340
1.5180	85.175	15.487
1.6620	96.790	15.572
1.8210	111.13	15.886
1.9651	126.03	16.219

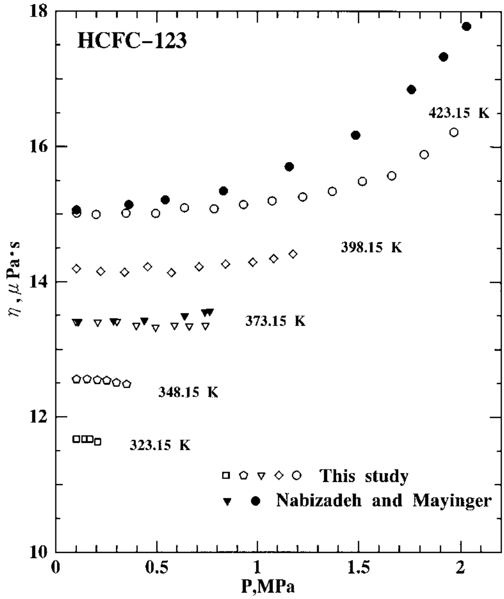

Fig. 1. Viscosity of HCFC-123 as a function of pressure.

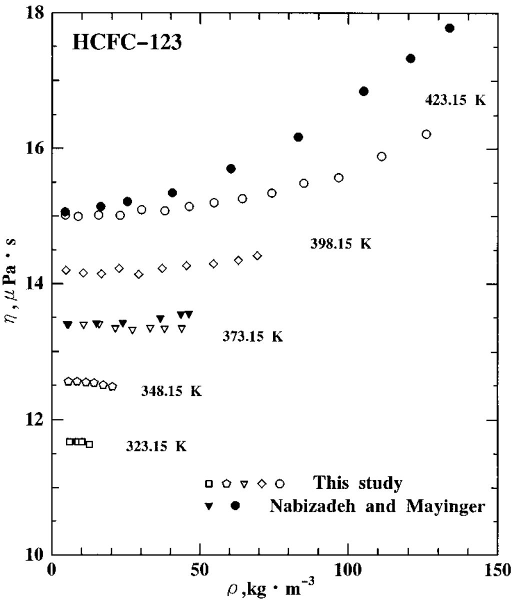

Fig. 2. Viscosity of HCFC-123 as a function of density.

[13, 14]. For comparison, the viscosity values at 373 and 423 K reported by Nabizadeh and Mayinger [5] are also plotted in Figs. 1 and 2. While good agreement is obtained for the viscosity at 0.1 MPa, the viscosity values of Nabizadeh and Mayinger [5] for the compressed gas show a stronger density and/or pressure dependence than the present results. Almost the same results have been observed for the gaseous viscosity of R-407C and R-404A [15, 16].

REFERENCES

1. N. Shibasaki-Kitakawa, M. Takahashi, and C. Yokoyama, *Int. J. Thermophys.* **19**:1285 (1998).
2. M. Takahashi, C. Yokoyama, and S. Takahashi, *J. Chem. Eng. Data* **32**:98 (1987).
3. T. Takahashi, C. Yokoyama, and S. Takahashi, *Proc. 11th Japan Symp. Thermophys. Prop. Tokyo* (1990), pp. 115–118.
4. D. C. Dowdell and G. P. Matthews, *J. Chem. Soc. Faraday Trans.* **89**:3545 (1993).
5. H. Nabizadeh and F. Mayinger, *High Temp.-High Press.* **24**:221 (1992).
6. Y. Tanaka and T. Sotani, *Int. J. Thermophys.* **17**:293 (1996).
7. B. A. Younglove and M. O. McLinden, *J. Phys. Chem. Ref. Data* **23**:731 (1994).
8. G. F. Newell, *ZAMP* **10**:160 (1959).
9. K. Stephan, R. Krauss, and A. Laesecke, *J. Phys. Chem. Ref. Data* **16**:993 (1987).
10. R. T. Jacobsen and R. B. Stewart, *J. Phys. Chem. Ref. Data* **2**:757 (1973).
11. M. Takahashi, C. Yokoyama, and S. Takahashi, *Trans. JAR* **4**:25 (1987).

12. M. Takahashi, N. Shibasaki-Kitakawa, C. Yokoyama, and S. Takahashi, *J. Chem. Eng. Data* **40**:900 (1995).
13. E. Vogel, E. Bich and R. Nimz, *Physica A* **139**:188 (1986).
14. E. Vogel, B. Holdt, and T. Strehlow, *Physica A* **148**:46 (1988).
15. M. Takahashi and C. Yokoyama, *Proc. 39th High Press. Conf., Nara, Japan* (1998), p. 233 (3D06).
16. M. Takahashi, T. Nishino, and C. Yokoyama, *Proc. 40th High Press. Conf., Fukuoka, Japan* (1999), p. 277 (3C15).