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Measurement of the Viscosity of HCFC 123 in the Temperature Range 233–418 K and at Pressures up to 20 MPa

T. Okubo[1] **and A. Nagashima**[1]

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The viscosity of HCFC 123 was measured over the range of temperature from 223 to 418 K and pressure up to 20 MPa. The experimental method was that of the capillary flow and a closed-circuit high-pressure viscometer was used. The sample fluid was circulated through a Pyrex glass capillary from a high-pressure plunger system. The constant of the Pyrex glass capillary was calibrated against the reference standard, pure water. The viscosity of the sample was calculated from the flow rate, the pressure drop at the capillary, and the capillary constant using the Hagen–Poiseuille equation. Measurements were made on seven isotherms. In the case of the transpiration method, the density is needed for calculation of the viscosity from the kinematic viscosity. The available density data of HCFC 123 are less reliable than those for CFC 11. Therefore, uncertainty in the viscosity of HCFC 123 is larger, although the measured kinematic viscosity itself has a reproducibility of 0.1 %. HCFC 123 is proposed as an alternative to CFC 11. Comparisons of the data for these two substances show that the viscosity of HCFC 123 is similar in magnitude to that of CFC 11 at temperatures around 350 K, higher at lower temperatures, and lower at higher temperatures. The pressure gradients for these two corresponding substances are similar over the entire temperature range.

KEY WORDS: capillary viscometer; 1,1-dichloro-2,2,2-trifluoroethane; HCFC 123; viscosity.

1. INTRODUCTION

Chlorofluorocarbons (CFCs) are used as working fluids for heat pumps, air conditioners, refrigerators, and other applications due to such favorable characteristics as high thermal conductivity, high density, low viscosity, no

[1] Department of Mechanical Engineering, Keio University, Hiyoshi, Yokohama 223, Japan.

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virulence, and chemical stability. However, some CFCs have been blamed for ozone depletion and the greenhouse effect. Also, their high stability is a major cause of pollution. To alleviate the situation, CFC alternatives including hydrogen-containing halocarbons have been proposed. The study of the properties of these substances is urgently needed.

In the present study, the viscosity of HCFC 123 (1,1-dichloro-2,2,2-trifluoroethane, $CHCl_2CF_3$), which is the alterative to CFC 11, was measured over the temperature range 233–418 K and at pressures up to 20 MPa.

2. EXPERIMENTS

The experimental method was that of the capillary method and a closed-circuit capillary viscometer was used. The experimental system was similar to those used for other fluids under high pressure in our laboratory in the past. Details of the technique and the apparatus are given in previous publications [1, 2]. The viscosity was calculated using a modified Hagen–Poiseuille equation,

$$\eta = \frac{\pi C \, \Delta P (1 + \alpha \, \Delta t)^3}{8Ql} - \frac{m\rho Q}{8\pi l (1 + \alpha \, \Delta t)} \tag{1}$$

where η is the viscosity in Pa · s, ΔP is the pressure drop in Pa, C is the capillary constant in m^4, Q is the volumetric flow rate in $m^3 \cdot s^{-1}$, l is the length of the capillary in m, α is the thermal expansion coefficient of the capillary in K^{-1}, ρ is the density of the sample fluid in $kg \cdot m^{-3}$, and m is the kinetic-energy correction factor ($m = 1.12$). The capillary constant, C, was determined by calibrating the capillary against the viscosity of water in the Ref. 3.

The experimental apparatus is a closed-circuit high-pressure capillary viscometer, as shown in Fig. 1. The capillary used in the present measurements is made of Pyrex glass which has a length of 300 mm and an inner diameter of about 0.3 mm. The capillary cell is shown in Fig. 2.

The middle part of the capillary cell is connected by joints and the capillary is fixed by using PTFE packings. The fluid was circulated from one end of a twin-headed injector (Fig. 1), through the capillary, to the other end of the injector. The pressure drop between the two ends of the capillary was measured by a high-pressure mercury manometer with a traveling microscope. The volumetric flow rate, Q, was determined by counting the movement of the plunger of the circulation injector. The pressure of the sample was measured by a Bourdon gauge and the temperature at the capillary was measured with a Pt thermoresister which was calibrated according to IPTS-68.

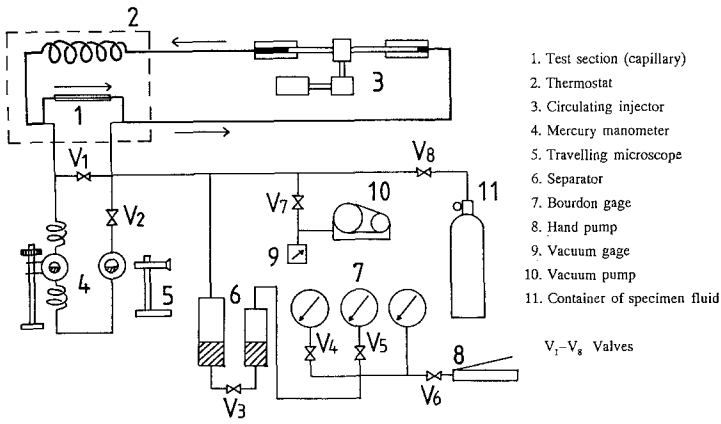
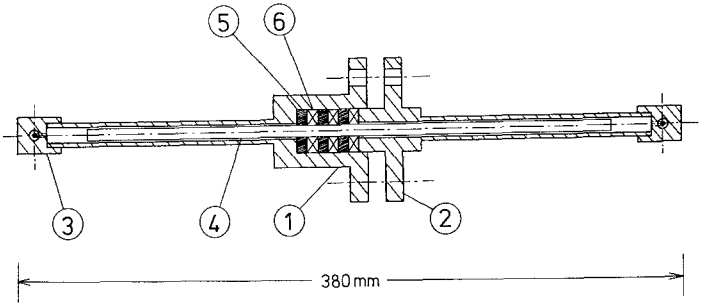


Fig. 1. Experimental apparatus.

The sample fluid, HCFC 123, was manufactured by Asahi Glass Company. The purity is 99.77 wt% HCFC 123. Impurities are residua-after-evaporation of less than 1 ppm, acids of less than 0.2 ppm, and H_2O of 2 ppm. The sample fluid was introduced into the viscometer circuit after evacuating the system.

In this study, the density value of the sample is needed for the calculation of the viscosity since the quantity directly measured is the kinematic viscosity. There are some data sources of the density of HCFC 123. However, few of them meet the range of the present measurements. So we examined values extrapolated from empirical correlations for the density of



1. Pressure vessel A
2. Pressure vessel B
3. Joint for connecting with tubing
4. Capillary
5. Spacer
6. Packing

Fig. 2. Capillary and test section.

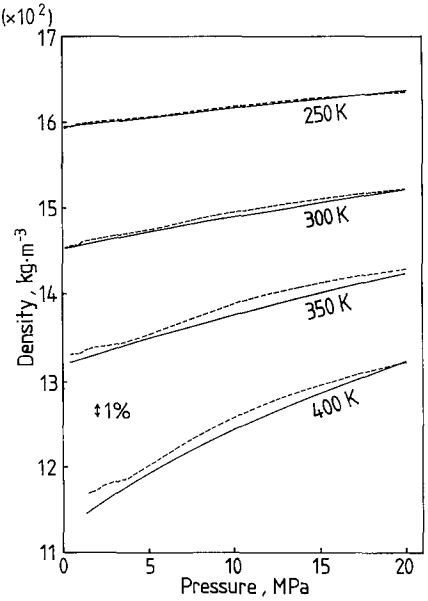


Fig. 3. Comparison of the calculated density values of Yen–Woods [4] (---) and Kumagai [5] (——) for HCFC 123.

HCFC 123 by comparing with the Tait equation and the Yen–Woods method [4]. Kumagai's method [5] was applied to determine the Tait parameters, which are based on the van der Waals-type model for the specific volumes of compressed liquid of halogenated hydrocarbons.

The standard deviation between the values of the density acquired from experimental studies [6, 7] and those from the Tait equation was 0.2% and the maximum deviation was −0.5%; similarly those between the experimental studies and the Yen–Woods method were 0.8 and 2.1%, respectively. The similar tendency of those two calculated values of the density in the range of the present measurement of the viscosity can be seen in Fig. 3. Judging from these comparisons, we decided to use the Tait equation, given by Eq. (2), for the density to convert the kinematic viscosity into viscosity. The error in the viscosity caused by the calculation of the density is estimated to be less than 1%. The Tait equation is

$$V = V_S\left(1 - C \ln \frac{B+P}{B+P_S}\right)$$
$$\rho = 1000M/V \tag{2}$$

where V is the specific volume of HCFC 123 in $cm^3 \cdot mol^{-1}$, V_S is the specific volume of the saturated liquid in $cm^3 \cdot mol^{-1}$, P is the pressure

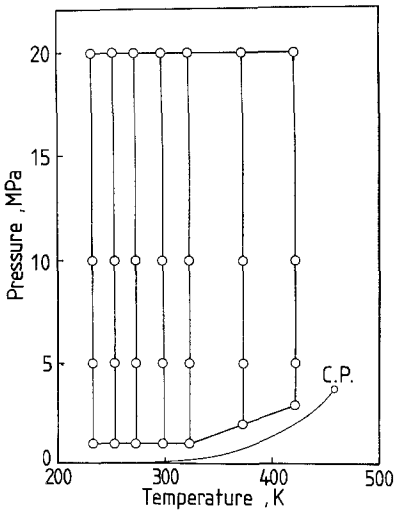


Fig. 4. Range and grid points of the present measurements.

in Pa, P_S is the saturated vapor pressure in Pa, M is the molecular weight in $g \cdot mol^{-1}$, and B and C are the Tait parameters.

The measurements took place at 28 grid points in the temperature range 233–418 K and at pressures up to 20 MPa. The grid points where the viscosity of HCFC 123 were measured in the experiments are shown in Fig. 4. The measurements were done on seven isotherms, namely, −40, −20, 0, 25, 50, 100, and 145°C. And at each temperature, measurements were made at 1–3, 5, 10, and 20 MPa. The viscosity measurements were repeated twice at each point, and if the deviation exceeded ±0.5% a third measurement was added.

3. RESULTS AND DISCUSSIONS

The values of the viscosity of HCFC 123 as well as the density and the kinematic viscosity measured in the present study are given in Table I. Error in the measurement of the pressure drop was ±0.3% and that in the flow rate was ±0.2%. Error in the capillary constant C was estimated as ±0.4%. Thus the estimated accuracy of the measurement, ignoring the error of the density, was estimated as ±1.2%. The pressure dependence of the viscosity of HCFC 123 is shown in Fig. 5. At lower temperatures, the temperature dependence is more significant, and the pressure dependence is similar to that for the viscosity of other normal liquids.

Table I. Experimental Results of the Viscosity of HCFC 123

Temperature T (K)	Pressure P (MPa)	Density ρ (kg·m^{-3})	Viscosity η (10^{-4} Pa·s)	Kinematic viscosity ν (10^{-7} m^2·s^{-1})
		Nominal temperature 233 K		
233.00	1.22	1652.6	10.61	6.420
232.99	1.17	1652.5	10.59	6.406
232.94	5.80	1661.4	11.08	6.669
232.96	5.84	1661.5	11.07	6.663
232.98	10.89	1670.7	11.61	6.946
232.99	10.79	1670.5	11.61	6.949
232.96	20.45	1687.6	12.60	7.466
232.96	20.16	1687.1	12.54	7.432
		Nominal temperature 253 K		
253.39	1.13	1586.5	7.563	4.767
253.41	1.16	1586.5	7.547	4.757
253.38	5.03	1595.7	7.860	4.925
253.40	5.10	1595.8	7.851	4.920
253.41	10.99	1609.0	8.300	5.158
253.42	11.10	1609.3	8.274	5.141
253.41	20.35	1629.0	8.950	5.494
253.40	20.26	1628.8	8.969	5.506
		Nominal temperature 273 K		
272.93	1.19	1530.2	5.763	3.766
272.88	1.36	1530.8	5.764	3.765
272.93	5.65	1542.8	6.009	3.895
272.91	5.61	1542.7	6.015	3.899
272.87	10.69	1556.5	6.344	4.076
272.85	10.94	1557.2	6.348	4.076
272.89	20.41	1580.9	6.930	4.384
272.89	20.45	1581.0	6.893	4.360
272.88	20.41	1580.9	6.899	4.364
		Nominal temperature 298 K		
298.48	1.24	1462.9	4.220	2.885
298.48	1.21	1462.8	4.220	2.885
298.50	6.09	1480.1	4.472	3.021
298.51	6.31	1480.8	4.477	3.023
298.10	9.67	1493.1	4.665	3.124
298.09	9.66	1493.0	4.610	3.088
298.48	10.73	1495.6	4.668	3.121
298.04	18.88	1521.8	5.134	3.374
298.10	18.88	1521.7	5.113	3.360
298.51	19.96	1524.0	5.078	3.332
298.45	20.38	1525.4	5.114	3.352

Table I. (*Continued*)

Temperature T (K)	Pressure P (MPa)	Density ρ (kg·m^{-3})	Viscosity η (10^{-4} Pa·s)	Kinematic viscosity ν (10^{-7} m^2·s^{-1})
		Nominal temperature 324 K		
323.91	1.09	1397.3	3.241	2.319
323.91	1.06	1397.1	3.220	2.304
323.88	5.56	1417.5	3.403	2.401
323.90	5.56	1417.5	3.417	2.411
323.70	9.96	1436.4	3.603	2.508
323.73	10.14	1437.1	3.613	2.514
323.83	20.50	1475.7	4.012	2.719
323.84	20.25	1474.9	3.981	2.699
323.85	20.05	1474.1	3.988	2.705
		Nominal temperature 372 K		
372.29	2.06	1263.7	2.018	1.597
372.28	2.06	1263.7	2.017	1.596
372.26	4.94	1286.4	2.143	1.666
372.26	4.98	1286.7	2.136	1.660
372.21	10.94	1327.5	2.382	1.794
372.22	10.97	1327.7	2.375	1.789
372.25	20.65	1382.5	2.718	1.966
372.26	20.57	1382.1	2.722	1.970
		Nominal temperature 418 K		
418.41	3.35	1089.5	1.261	1.157
418.40	3.29	1088.4	1.258	1.156
418.41	5.61	1129.2	1.394	1.235
418.41	5.61	1129.2	1.379	1.222
418.42	5.61	1129.1	1.380	1.222
418.35	10.11	1191.6	1.597	1.340
418.42	10.15	1192.0	1.597	1.340
418.46	19.95	1290.1	1.959	1.518
418.46	19.87	1289.5	1.953	1.514

Equation (3) was correlated from the values in Table I,

$$\eta = A + BP_r - \frac{T_r}{C + DT_r + P_r}$$

$$A = \sum_{i=0}^{3} a_i \exp \frac{i}{T_r}, \qquad B = \sum_{i=0}^{3} b_i \exp \frac{i}{T_r} \tag{3}$$

$$T_r = T/T_C, \qquad P_r = P/P_C$$

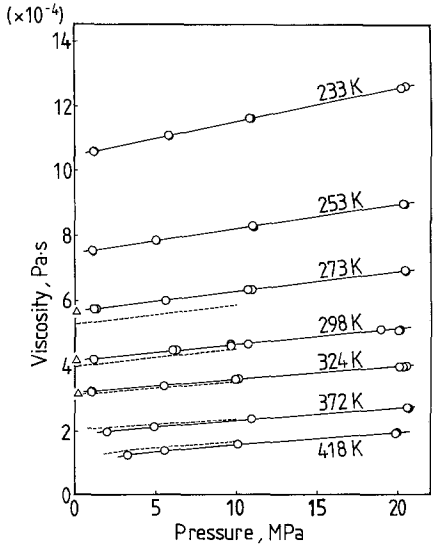


Fig. 5. Viscosity of HCFC 123. (○, ——) Present work; (△) saturated liquid [8]; (---) CFC 11 [1].

where the values of a_i, b_i, C, and D are given in Table II, η is the viscosity of HCFC 123 in $\times 10^{-4}$ Pa·s, T_C is the critical temperature (456.94 K [6]), and P_C is the critical pressure (3.672 MPa [6]). As the viscosity is almost linear in temperature for a given pressure, the equation is based on a linear function of a pressure and corrected by considering the tendency in the region close to the critical point. This equation can be used over a range of temperatures from 220 to 420 K and pressure up to 20 MPa

Table II. Coefficients of Eq. (3)

$a_0 = -2.50589$
$a_1 = 1.35065$
$a_2 = -5.42422 \times 10^{-2}$
$a_3 = 1.72102 \times 10^{-2}$
$b_0 = 1.66663 \times 10^{-1}$
$b_1 = -5.37335 \times 10^{-2}$
$b_2 = 1.12667 \times 10^{-2}$
$b_3 = 5.53930 \times 10^{-5}$
$C = 16.2472$
$D = -15.7246$

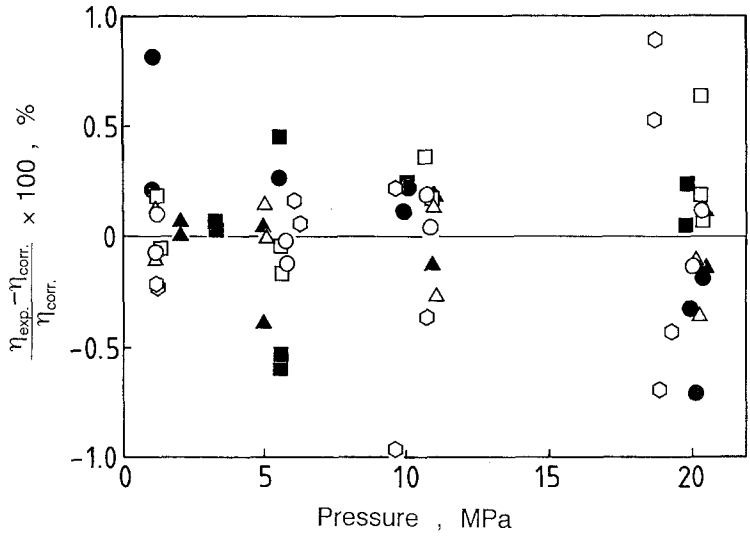


Fig. 6. Deviation of the experimental data from Eq. (3) for HCFC 123. (○) 233 K; (△) 253 K; (□) 273 K; (⬡) 298 K; (●) 324 K; (▲) 372 K; (■) 418 K.

(possibly to a little higher pressure). Figure 6 shows the deviations of the experimental data from Eq. (3). The standard deviation is 0.33% and the maximum deviation is 0.96%. Therefore, the deviations of all the experimental data from the correlation are within the estimated accuracy.

The experimental and calculated viscosities of the present study together with those of another study as well as the viscosity of CFC 11 are shown in Fig. 5. The results of the measurements of saturated liquid by Kumagai and Takahashi [8] agreed with the values obtained in the present study. The results for CFC 11 obtained by Nagashima et al. [1] are shown. In this case the two values agree around 350 K, and at temperatures lower than 350 K the viscosity of HCFC 123 is higher than that of CFC 11. The difference increases as the temperature decreases. The opposite situation occurs when the temperature is higher than 350 K.

4. CONCLUSIONS

In the present study, the viscosity of the liquid HCFC 123 was determined using a closed-circuit capillary viscometer under high pressure and over a wide temperature range. The largest error source was the uncertainty in density estimations. The results provide a new experimental data set for HCFC 123 covering a wide range of temperature and pressure to compare with its counterpart, CFC 11.

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