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MEASUREMENT OF ISOBARIC SPECIFIC HEAT OF HCFC-123 IN THE LIQUID PHASE

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SUMMARY

The isobaric heat capacity, *Cp*, of HCFC-123 which is a prospective alternative to CFC-11 has been measured by using a flow-calorimeter in the liquid phase. Sixty-nine *Cp* values have been determined at temperatures from 276 K to 410 K and pressures from 0.5 MPa to 3.0 MPa. The uncertainty was estimated being within ±10 mK in temperature, ±2 kPa in pressure and ±0.4 % in *Cp*, respectively. A *Cp* correlation which is effective in the experimental range has been also developed.

INTRODUCTION

It is our urgent task to develop stratospherically safe CFC(chlorofluorocarbon) alternatives. HCFC-123($CHCl_2CF_3$) is one of the prospective alternatives to replace CFC-11(CCl_3F) which has been widely used as a blowing agent and as a working fluid for turbo-compressor driven refrigeration machines and heat pumps. This paper reports the isobaric heat capacity data of liquid HCFC-123. The purity of HCFC-123 used in this study was 99.83 wt%.

PRINCIPLE AND APPARATUS

Isobaric specific heat is an important property for calculating thermodynamic performance or heat transfer problems for applications as a working fluid or a blowing agent, but it is not easy to get the values by predictions or calculations from a thermodynamic equation of state developed on the basis of *PVT* property data. The most reliable specific heat values are not determined theoretically but experimentally in the liquid phase, especially at high pressures. We selected flow-calorimetry for determining the

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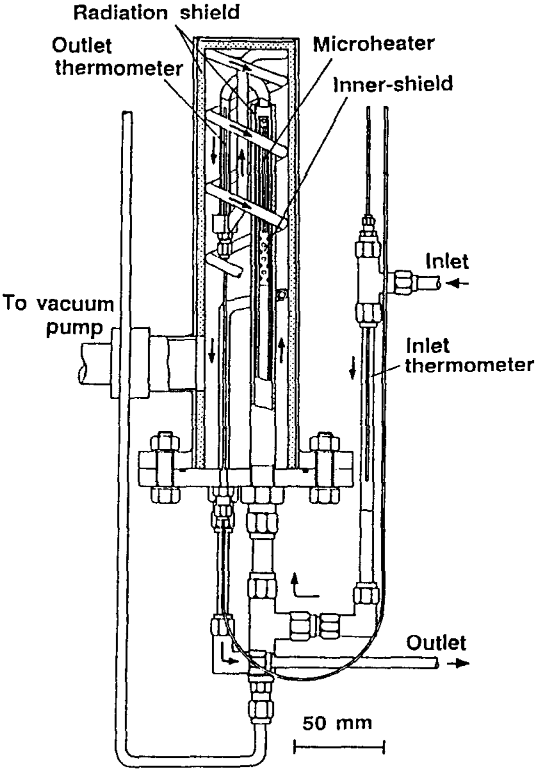

Fig. 1. Cross-section of the calorimeter.

absolute values of specific heat of liquids. This method can compensate the amount of heat leakage by measuring at various mass-flow rates of sample liquid. We have already measured isobaric specific heats for CFC-114(1) and HFC-134a(2) in their liquid phases with the uncertainties of ±0.4 % and ±0.3 %, respectively. The main part of calorimeter is shown in Fig. 1. A 5.5 Ω microheater sheathed in SUS316 tubing whose outer diameter is 1.6 mm is inserted at the center of 9.35 mm outer diameter stainless steel tubing and supplies heat flux to sample fluid. Two 100 Ω platinum resistance thermometers sheathed in SUS316 tubing whose outer diameter is 1.6 mm are placed at the center of 6.35 mm outer diameter stainless steel tubing as inlet and outlet thermometers. They were calibrated according to IPTS-68. A detailed explanation of the present apparatus has been published previously(3).

The flow-calorimetry consists of three simultaneous measurements; mass-flow rate $\dot{m}$, heat flux $\dot{Q}$, and temperature increment ΔT. Specific heat Cp is determined by the following relation;

$$Cp = \dot{Q} / (\dot{m} \, \Delta T) \tag{1}$$

Equation (1) is true only in the case of an ideal condition without heat loss nor temperature change due to sample liquid flowing. The heat leakage is compensated by performing plural measurements with different mass-flow rates. Figure 2 shows typical example of measured Cp including heat loss versus reciprocal of mass-flow rate. By taking the heat loss $\dot{Q}_L$ into consideration, Eq. (1) becomes,

$$Cp = \dot{Q} / (\dot{m}\,\Delta T) + \dot{Q}_L / (\dot{m}\,\Delta T). \tag{2}$$

where $\dot{Q}_L$ will be eliminated at the infinitely large mass-flow rate, or by reducing $\dot{Q}_L$ itself. The heat loss appears as a slope of the lines in Fig. 2.

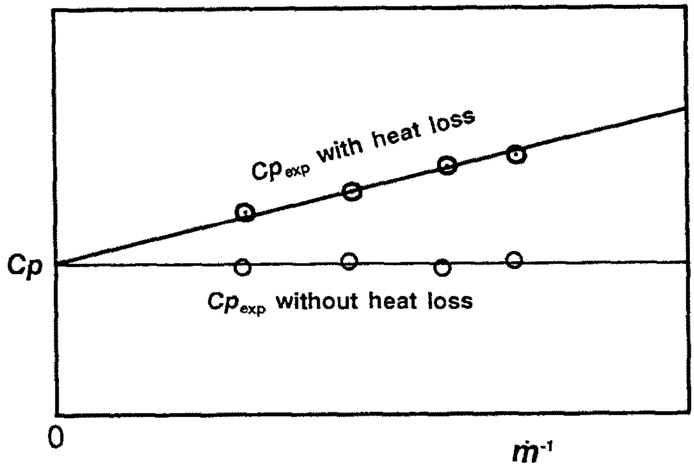

Fig. 2. Relation between the measured specific heat values, Cp_{exp}, and the reciprocal of mass-flow rate, $\dot{m}^{-1}$, in flow-calorimetry.

The temperature change due to sample liquid flowing was very small in the present measurements because the maximum flow rate was 0.16 g/s. The temperature increment ΔT was controlled to be 5 K by regulating the heat flux $\dot{Q}$. The temperature change was always monitored by measuring temperature difference between inlet and outlet thermometers without heating by microheater at the same temperature, pressure, and mass-flow rate as those of measurements associated with heating. The temperature increment ΔT in Eq. (1) was determined from the sum of those temperature differences between inlet and outlet thermometers in both cases of the processes with heating and without heating by microheater. This process compensates the temperature change due to sample liquid flowing and other effects. The maximum temperature change between inlet and outlet thermometers in the case of the process without heating was about 40 mK at higher temperatures.

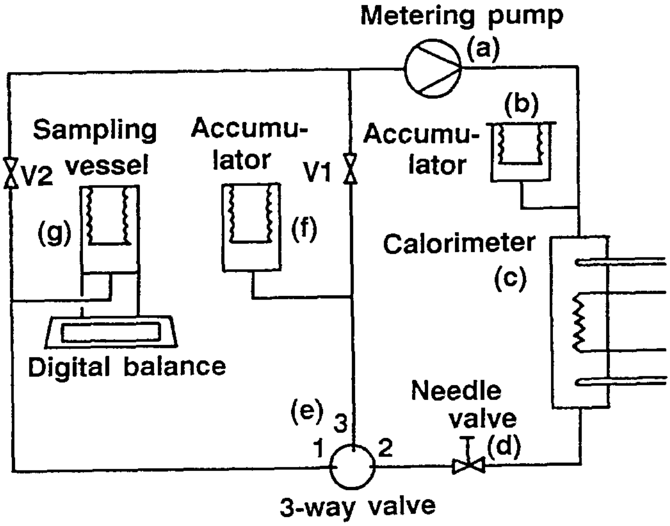

Fig. 3. Flow assembly.

A schematic diagram of flow assembly is shown in Fig. 3. The sample fluid is filled in the system completely in the liquid phase. The sample liquid is circulated in the system by a metering pump (a), where the pulsation due to the metering pump is absorbed by means of the metallic bellows installed in sampling vessel (g) and accumulators, (b) and (f). The sample pressure is controlled by means of the pressure of nitrogen gas filled in metallic bellows of accumulator (b). The sample fluid flows from the accumulator (b) to the sampling vessel (g) or accumulator (f) through calorimeter (c) and needle valve (d). The calorimeter is installed in a thermostated bath where the temperature is controlled within ±5 mK at a required temperature. The mass-flow rate is determined from mass difference of sampling vessel (g) placed on a digital balance and the time period.

MEASUREMENTS

The measurements were performed at temperatures from 275.65 K to 410 K and

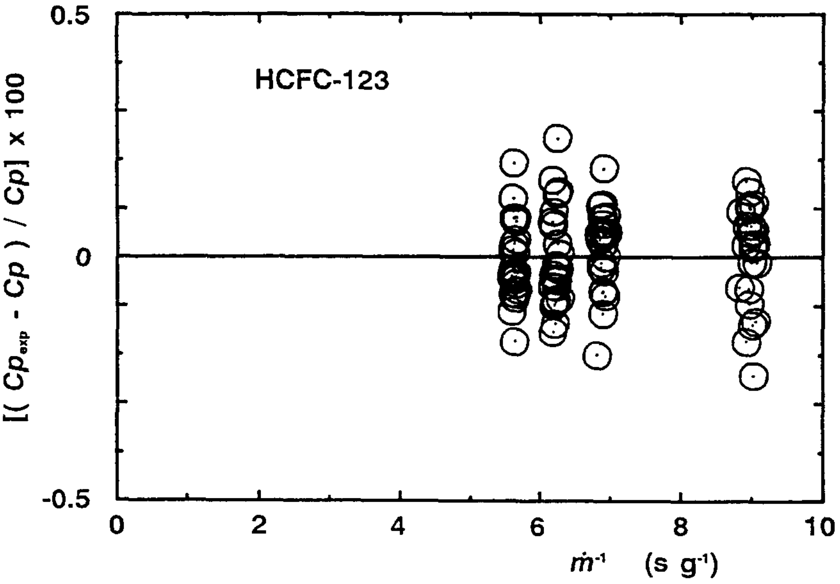

Fig. 4. **The present *Cp* measurements at reciprocal of various mass-flow rates.**

pressures from 0.5 MPa to 3.0 MPa. In order to know the effect of heat loss in the measured *Cp* values, 138 data were measured at various mass-flow rates which were plotted against the reciprocals of mass-flow rate in Fig. 4. Sixty-nine final results were determined from the 138 measurements. The uncertainty of the measurements is better than ±10 mK in temperature increment, ±0.02 % in heat flux, ±0.2 % in mass-flow rate, and ±10 mK in temperature, and ±2 kPa in pressure, respectively. The overall uncertainty of determined *Cp* values is concluded to be better than ±0.4 %. These results are plotted in Fig. 5.

DISCUSSIONS

Figure 4 shows the present measurements against the reciprocal of mass-flow rate. The specific heat values do not depend upon the mass-flow rates which means heat loss in the present measurements is small enough to determine the specific heat values with the uncertainty of ±0.4 % as discussed above.

A correlation was developed on the basis of the data measured in the liquid phase by least squares fitting with simple polynomials;

$$Cp = A(T)P + B(T) \tag{3}$$

$A(T) = a_1/(1 - Tr) + a_2/(1 - Tr)^{0.5}$

$B(T) = b_1/(1 - Tr)^{1.5} + b_2/(1 - Tr) + b_3/(1 - Tr)^{0.5}$

$a_1 = -0.005177$ $a_2 = 0.007561$

$b_1 = 0.05824$ $b_2 = -0.4027$ $b_3 = 1.1235$

where P and Tr denote pressure in MPa and temperature of $Tr = T / Tc$, respectively, and Cp is given in kJ/(kg K). The critical temperature Tc is 456.86 K which reported by Tanikawa et al.(4) Equation(3) is effective in a range of temperatures between 275.65 K and

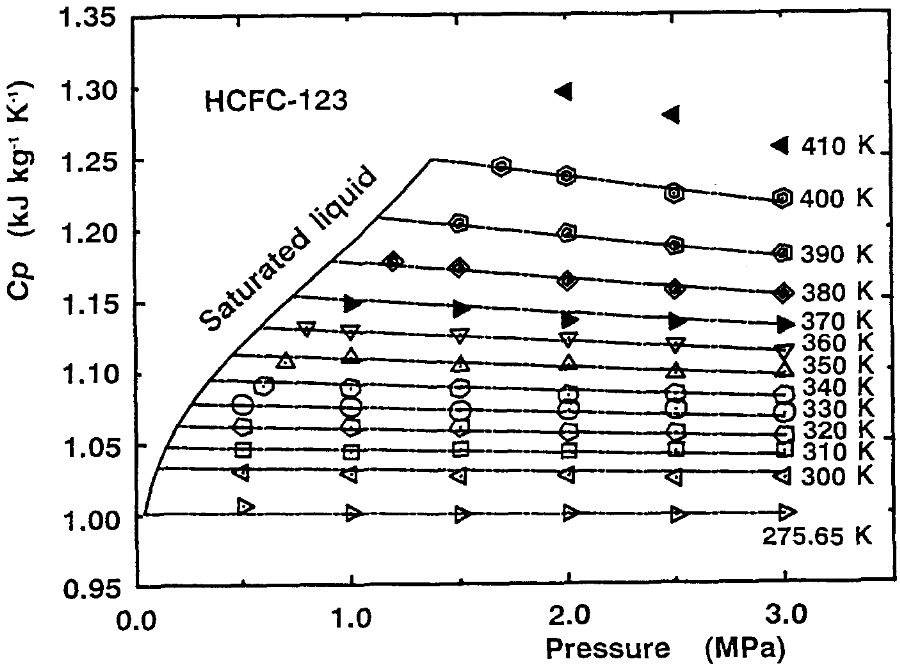

Fig. 5. Experimental data and the correlation for the isobaric specific heat of liquid HCFC-123.

400 K and pressures up to 3 MPa. The uncertainty of calculated *Cp* values from Eq. (3) is estimated better than ±0.6 %. Equation (3) is compared with the experimental data in Fig. 5. The *Cp* values of saturated liquid HCFC-123 calculated from Eq. (3) at the vapor pressures reported by Piao et al.(5) are also given in Fig. 5 and these values are compared with those of CFC-11(6) in Fig. 6 for the practical use of HCFC-123 as an alternative fluid to CFC-11.

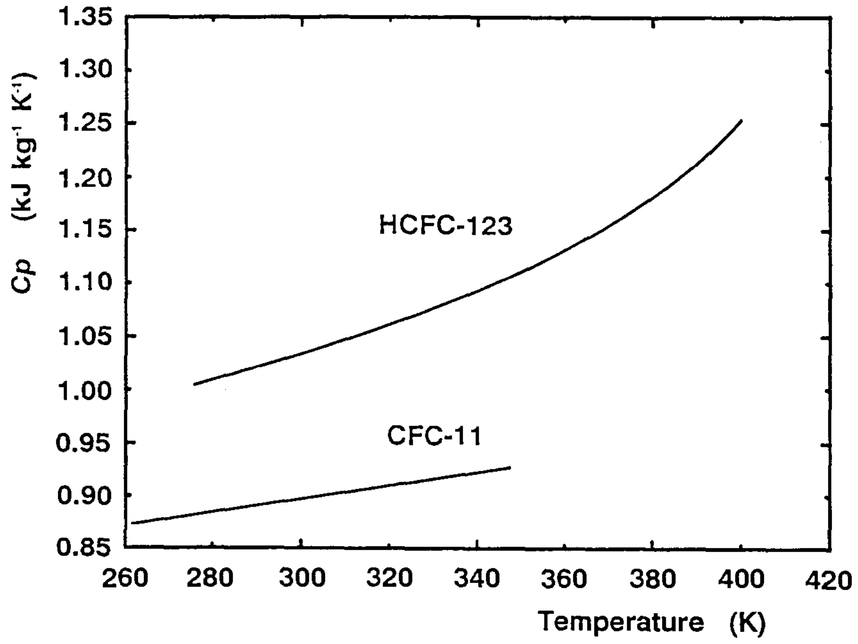

Fig. 6. Comparison of the present correlation for HCFC-123 with that of CFC-11(6) at the saturation states.

CONCLUSION

Isobaric specific heats of HCFC-123 were measured in the liquid phase at temperatures from 275.65 K to 410 K and pressures from 0.5 MPa to 3.0 MPa with the estimated uncertainty of ±0.4 %. The correlation which is effective in the range of temperatures between 275.65 K and 400 K, and pressures up to 3 MPa was also developed. The uncertainty of calculated specific heat values from the correlation is better than ±0.6 %.

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REFERENCES

1 H. Sato, N. Sakate, M. Ashizawa, M. Uematsu, and K. Watanabe, Measurement of the isobaric specific heat capacity for liquid dichlorotetrafluoroethane(R 114), Proc. 1987 ASME-JSME Therm. Eng. Joint Conf., 4 (1987) 351-358.

2 A. Saitoh, H. Sato, and K. Watanabe, Isobaric heat capacity data for liquid HFC-134a, submitted to J. Chem. Eng. Data, (1989).

3 A. Saitoh, H. Sato, and K. Watanabe, A new apparatus for the measurement of the isobaric heat capacity of liquid refrigerants, Int. J. of Thermophys., 10(3) (1989) 649-659.

4 S. Tanikawa, Y. Kabata, H. Sato, and K. Watanabe, Measurements of the vapor-liquid coexistence curve in the critical region of HCFC-123, Proc. 2nd Asian Thermophys. Prop. (1989) 513-518.

5 C.-C. Piao, H. Sato, and K. Watanabe, Measurements of the saturated vapor pressure and *PVT* property of HCFC-123, to be presented at the 1989 JAR Ann. Conf. (1989).

6 A. F. Benning, R. C. McHarness, W. H. Markwood, Jr., and W. J. Smith, Heat capacity of the liquid and vapor of three fluorochloromethanes and trifluorotrichloroethane, Int. Eng. Chem., 32(7) (1940) 976-980.