n are available in the literature (*1*, *5*), they agree with those in Table I within the stated experimental accuracies.

The solvents studied for this note all have relatively low refractive indices, enabling a Suprasil semicylinder to be used. For solvents with relatively large refractive indices, such as benzene and toluene, a semicylinder of some material having a larger refractive index such as sapphire must be used.

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Pressure–Volume–Temperature Relationships of Refrigerant 500 Gas

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The compressibility factors have been measured using a Burnett-type apparatus on Refrigerant 500 from 298.15 to 413.15 K and from 0.2 to about 7 bar. Refrigerant 500 is a minimum-boiling azeotrope of 26.2 wt % 1,1-difluoroethane (Refrigerant 152a) and 73.8 wt % of difluorodichloromethane (Refrigerant 12). The apparatus was calibrated with high-purity helium. The uncertainties in the measurements were estimated as follows: temperature, ±0.01 K; pressure, ±1 × 10^{-4} bar; compressibility factor, ±0.1%. The second virial coefficients are reported for helium and second and third virial coefficients for Refrigerant 500.

A Burnett-type apparatus (*3*) was fabricated and used to obtain compressibility factors of Refrigerant 500 gas at temperatures 298.15 K and from 313.15 to 413.15 K at 20 K intervals. The pressures at each temperature extended from about half the saturation pressure to about 0.2 bar. Refrigerant 500 is a minimum boiling azeotrope of 26.2 wt % 1,1-difluoroethane (Refrigerant 152a) and 73.8 wt % of difluorodichloromethane (Refrigerant 12). Recent applications of minimum boiling azeotropes to the vapor compression refrigeration systems have indicated their superiority over their pure constituents under identical conditions (*2*, *7*). While retaining the merits of pure component refrigerants, the use of minimum boiling azeotropes has resulted in increased capacity, attainment of lower temperatures, and as a consequence improved coefficient of performance.

The only literature *P*–*V*–*T* data for Refrigerant 500 are reported by Sinka and Murphy (*10*), which extend from 322 to 478 K, 14 to 58 bar, and 17 × 10^{-3} to 149 × 10^{-3} m^3 mol^{-1}.

Emphasis in this work has been on the low pressure *P*–*V*–*T* data primarily to obtain reliable values of second virial coefficients and to extend the range of existing *P*–*V*–*T* data on R-500 in the low pressure region.

Experimental Section

Materials Used. Helium of 99.99 mol % purity was obtained from the Low Temperature Laboratory, Indian Institute of Technology Kanpur, Kanpur, India. The purity was checked by gas–liquid chromatography and was found to comply with the above specifications. R-500 was of 99.95 mol % stated purity made by Du Pont and was supplied by the Universal Commercial Co., Bombay, India. It was used without further purification.

Apparatus. The Burnett apparatus used in this investigation was basically similar in design to that used by Anderson et al. (*1*) with some important modifications. The compressibility cell was machined from type 316 stainless steel. The finished cell was 0.1 m o.d. by 0.38 m long. The sample chamber V_I, 0.06 m o.d. by 0.245 m long (approximate volume, 888 × 10^{-6} m^3), and the expansion volume V_II, 0.06 m o.d. by 0.105 m long (approximate volume, 380 × 10^{-6} m^3), were bored from the opposite ends of the cell block. Eubank and Kerns (*4*) in their recent analysis of adsorption and molecular association in the Burnett apparatus have recommended the following modifications: (a) Type 303 stainless steel for the construction of the compressibility cell should be avoided as it gives a poor finish and consequently leads to adsorption, (b) elimination of usual tapers at the bottom of V_I and V_II, and (c) the surface of the cell should be superfinished. These modifications were incorporated in the design of the present apparatus. An excellent finish of the cell surface was obtained by special lapping process provided at the Indian Ordinance Factory, Kanpur, India.

Temperature Measurement. Temperatures were measured with chromel–constantan thermocouples (Thermoelectric Co.) which were directly exposed to the experimental gas. The emf was measured by a Type K-3 Universal potentiometer (Leeds and Northrup) and a L&N 2430 DC galvanometer assembly. Four thermocouples were used; two were placed in the cell, the third was located inside the oil bath very close to the compressibility cell wall, and the fourth, a movable one, was used to check the temperature gradient inside the bath. All the thermocouples were calibrated against a 25-Ω platinum resistance thermometer and a resistance bridge assembly (both L&N). The uncertainty in the temperature measurement was estimated to be ±0.01 K.

Pressure Measurement. Pressures from 3 to 29 bar were measured by a Ruska dead-weight gauge and from 0.14 to 2 bar by a Ruska air piston gauge. The pressure balance was achieved through a Ruska differential pressure indicator (DPI). The DPI was a low-temperature DPI and hence had to be placed outside the bath, in a small insulated enclosure which was maintained at 298.15 ±1 K. The uncertainty in the final pressure measurement was estimated to be 1 × 10^{-4} bar. Atmospheric pressures were read with a mercury barometer with an accuracy of ±6.8 × 10^{-7} bar.

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Table I. Cell Constant N Using Helium

T, K	N	T, K	N
298.15	1.433 91	373.15	1.433 82
333.15	1.433 89	393.15	1.433 81
353.15	1.433 86	413.15	1.433 78

Table II. Comparison of Second Virial Coefficients for Helium

T, K	$10^6 B_v$, m^3 mol^{-1}	Reference
298.15	11.60	Present work
	11.74	Michels, Wouters (*8*)
333.15	11.48	Present work
	11.55[a]	Michels, Wouters (*8*)
353.15	11.42	Present work
	11.45[a]	Michels, Wouters (*8*)
373.15	11.30	Present work
	11.36	Kudchadker (*6*)
	11.31	Silberberg et al. (*9*)
	11.34	Michels, Wouters (*8*)
	11.15	Tanner, Masson (*11*)
	11.31	Wiebe, Gaddy, Heins (*12*)
393.15	11.20	Present work
	11.24[a]	Michels, Wouters (*8*)
413.15	11.15	Present work
	11.13[a]	Michels, Wouters (*8*)

[a] Interpolated values.

Experimental Results

A. Helium Calibration. The apparatus was calibrated with helium for isotherms at 298.15 K and from 333.15 to 413.15 K at 20 K intervals. One run was made at each temperature and the pressures ranged from about 0.2 to about 21 bar. The data were analyzed using the procedure of Hall and Canfield (*5*) which produces apparatus constants and virial coefficients consistent with the data within least mean squares. At temperatures greater than 298.15 K, the DPI correction (*6*) was applied because the DPI was placed outside the bath. Values of the cell constants at the experimental temperatures using helium are reported in Table I. The resulting second virial coefficients, B_v, m^3 mol^{-1}, are compared with the literature values in Table II. The agreement is satisfactory.

B. Refrigerant 500. Compressibility factor isotherms were measured at 298.15 K and from 313.15 to 413.15 K at 20 K interval for pressures up to 7 bar. At each temperature the maximum pressure was less than half the saturation pressure to minimize adsorption effects. Three runs were made at each isotherm except at 413.15 K in order to give evenly spaced data points. At 413.15 K only two runs were made. The data were analyzed in the same manner as was done for helium. The compressibility factors, reported in Table III are available in the supplementary material. The second and third virial coefficients are reported in Table IV. The extent of the DPI correction at two temperatures is reported in Table V.

The effect of systematic error in the pressure measurements on the compressibility factors and the virial coefficients was calculated according to Hall and Canfield (*5*). The maximum uncertainty in the compressibility factor was estimated to be about 0.1%. The uncertainties in B_v and C_v are estimated to be $\pm 2 \times 10^{-6}$ m^3 mol^{-1} and 25×10^{-12} (m^3 mol^{-1})^2, respectively.

Comparison

The only comparison that can be made is with the extrapolated values of Sinka and Murphy using their equation of state. The comparison at two typical temperatures at selected volumes is reported in Table V. In general the deviation in compressibility factors is about 0.7% at the highest pressures reducing to about 0.1% at the lowest pressures. Further work is in progress to develop an equation of state to represent adequately both sets of P-V-T data.

Table IV. Second and Third Virial Coefficients of Refrigerant 500

T, K	$10^6 B_v$, m^3 mol^{-1}	$10^{12} C_v$, (m^3 mol^{-1})^2
298.15	−365.5	−544 540
313.15	−334.1	−457 460
333.15	−299.3	−352 510
353.15	−267.5	−250 120
373.15	−237.5	−159 990
393.15	−212.1	−82 120
413.15	−190.0	−25 020

Table V. Extent of the DPI Correction in the Compressibility Factors, and Comparison of the Present Data with Those of Sinka and Murphy

		P, bar		Z	
T, K	$10^3 V$, m^3 mol^{-1}	This work	Sinka, Murphy[a]	Exptl	Cor[b]
313.15	3.067	7.3734	7.4223	0.8680	0.8686
	4.419	5.3637	5.3734	0.9100	0.9104
	6.344	3.8553	3.8514	0.9391	0.9393
	13.051	1.9393	1.9347	0.9721	0.9721
	18.667	1.3682	1.3653	0.9809	0.9809
	26.883	0.9559	0.9542	0.9870	0.9870
	38.495	0.6703	0.6694	0.9910	0.9910
	55.076	0.4698	0.4693	0.9938	0.9938
	78.725	0.3293	0.3290	0.9957	0.9957
413.15	4.787	6.9022	6.8815	0.9607	0.9619
	6.701	4.9834	4.9754	0.9718	0.9721
	9.747	3.4560	3.4526	0.9805	0.9806
	19.979	1.7030	1.7021	0.9904	0.9905
	28.549	1.1952	1.1948	0.9932	0.9933
	41.086	0.8322	0.8319	0.9953	0.9954
	58.862	0.5817	0.5815	0.9968	0.9968
	84.148	0.4073	0.4072	0.9977	0.9977

[a] Calculated from their equation of state. [b] DPI correction applied.

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Glossary

B_v	second virial coefficient, m^3 mol^{-1}
C_v	third virial coefficient, (m^3 mol^{-1})^2
N	cell constant
P	pressure, bar
T	temperature, K
V	specific volume, m^3 mol^{-1}
Z	compressibility factor

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Supplementary Material Available: Table S 3, compressibility factors of Refrigerant 500 (8 pages). Ordering information is given on any current masthead page.