the start of the measurement. We are not aware of literature values for either TTP or TCP.

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Literature Cited

(1) Gerritsen, L. A.; Scholten, J. J. F. (Organisatie voor Zuiver Wetenschappelijk Onderzoek) Netherlands Patent Applications 7 700 554 (**1977**), 7 712 648 (**1977**), and 7 902 964 (**1979**).
(2) Gerritsen, L. A.; Scholten, J. J. F. (Stamicarbon B.V.) German Patent Application 2 802 276 (**1978**) and British Patent Application 1 551 601 (**1979**).
(3) Forward, M. V.; Bowden, S. T.; Jones, W. J. *J. Chem. Soc.* **1949**, *5*, s121.
(4) de Kruif, C. G.; van Ginkel, C. H. D. *J. Chem. Thermodyn.* **1977**, *9*, 725.
(5) Clarke, E. C. W.; Glew, D. N. *Trans. Faraday Soc.* **1966**, *62*, 539.
(6) Ambrose, D.; Lawrenson, I. J.; Sprake, C. H. S. *J. Chem. Thermodyn.* **1975**, *7*, 1173.

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Low-Pressure Compression Factors for R-12 Gas

Mithileshwar Prasad[†]

Department of Mechanical Engineering, Indian Institute of Technology, Kanpur 208016, India

Low-pressure compression factors of R-12 gas have been measured by using an improved Burnett apparatus from 298.15 to 373.15 K and from 0.3 to above 5 bar. R-12 is an abbreviation for dichlorodifluoromethane, a refrigerant. The uncertainties in the measurements of pressure, temperature, and compression factor are estimated to be ±10^{-4} bar, ±0.01 K, and ±0.1%, respectively. The second virial coefficients for R-12 are reported.

The compression factor of a gas, defined as $Z = PV/(nRT)$, is a measure of its departure from ideality, and equation-of-state data are conveniently expressed in terms of Z values over a range of pressure and temperature.

The low-pressure compression factors of R-12 gas have been measured by using an improved Burnett apparatus. The details of the apparatus are described elsewhere (*1*, *2*). R-12 is a refrigerant, dichlorodifluoromethane. The literature on the experimental determination of the pressure–volume–temperature relationship of R-12 gas is limited to pressures above 5 bar (*3–7*). The only published second virial coefficients for R-12 are those by Kunz and Kapner (*8*), who have used the input data from ref *4*.

The objective of the present investigation was to obtain low-pressure compression factors for R-12 gas primarily to extend the range of existing $P-V-T$ data to the low-pressure region.

The Burnett apparatus (*9*) has been used repeatedly by several research workers for volumetric studies of various gases. A special feature of the apparatus lies in the fact that it dispenses with comparatively difficult measurements of mass and volume of the gas. Only pressure and temperature are needed to be measured, which can be done with relatively high accuracy. The basic design of the apparatus in most of the studies has been similar to that of Silberberg et al. (*10*). Eubank and Kerns (*11*) in their recent study have made salient recommendations to avoid adsorption and molecular association in the Burnett apparatus. All of the recommendations have been incorporated into the apparatus used for the present investigation (*1*, *2*).

The apparatus was calibrated with high-purity helium for isotherms at 298.15 K and from 313.15 to 413.15 K at 20 K intervals. The second virial coefficients for helium were determined and were compared with standard literature values (*1*). The agreement was found to be good. Pressure–volume–temperature relationships of Refrigerant 500 gas were measured with this apparatus (*2*).

The same apparatus as described above has been used for the compressibility study of R-12 gas at low pressures.

[†] Present address: Heat Transfer Section, Central Mechanical Engineering Research Institute, Durgapur 713209, India.

Results

Compression factors of R-12 gas were measured at 298.15 K and from 313.15 to 373.15 K at 20 K intervals for pressures from 0.3 to over 5 bar. Three runs were made at each isotherm to reduce the pressure gap between data points. The data reduction procedure described in ref *2* was used to obtain compression factors. These are reported in Table I. The uncertainties in the measurements were estimated to be ±0.01 K, ±10^{-4} bar, and ±0.1% for temperature, pressure, and compression factor, respectively.

The Berlin expansion of the virial equation of state was used to determine the second virial coefficient at each isotherm. This equation can be expressed as

$$(Z - 1)/P = B_p + C_pP + D_pP^2 + ... \quad (1)$$

where Z is the compression factor, P is the pressure, and B_p, C_p, D_p, etc., are second, third, fourth, and so on, virial coefficients, respectively, and are functions of temperature alone.

From eq 1

$$\lim_{P \to 0} (Z - 1)/P = B_p \quad (2)$$

The second virial coefficient, B_p, was determined graphically by extrapolating a large-scale, straight-line plot of $(Z - 1)/P$ vs. P to zero pressure at each temperature. Spurious points, if any, were ignored. Values of B_p are reported in Table II and are plotted in Figure 1 along with the results from Kunz and Kapner (*8*). The agreement between the two results is found to be good. The second virial coefficients computed in the present work are estimated to be accurate within ±2%.

Conclusion

Low-pressure compression factors of R-12 gas have been measured at moderate temperatures by using an improved Burnett apparatus to extend equation-of-state data to the low-pressure region. Second virial coefficients determined from these data compare well with the published literature values.

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Table I. Compression Factors of R-12 Gas

press., bar	compression factor	press., bar	compression factor
	Temp, 298.15 K, Run 1		
5.6721	0.8940	1.0322	0.9933
4.1321	0.9293	0.7328	0.9958
2.0964	0.9769	0.5219	0.9974
1.4870	0.9876	0.3775	0.9983
	Run 2		
5.2746	0.9056	0.9493	0.9940
3.8146	0.9369	0.6594	0.9964
1.9394	0.9800	0.4790	0.9977
1.3558	0.9895	0.3464	0.9985
	Run 3		
5.0443	0.9084	0.9052	0.9945
3.6460	0.9482	0.6336	0.9966
1.8526	0.9819	0.4547	0.9979
1.3101	0.9902		
	Temp, 313.15 K, Run 1		
5.4550	0.9172	0.9632	0.9956
3.9245	0.9447	0.6792	0.9975
1.9557	0.9851	0.4572	0.9986
1.3877	0.9917	0.3439	0.9991
	Run 2		
4.9650	0.9273	0.8728	0.9960
3.5550	0.9563	0.6046	0.9979
1.7918	0.9871	0.4280	0.9989
1.2425	0.9930	0.3141	0.9992
	Run 3		
4.7897	0.9309	0.8232	0.9967
3.3248	0.9608	0.5725	0.9983
1.6482	0.9888	0.4079	0.9990
1.1587	0.9939	0.2961	0.9993
	Temp, 333.15 K, Run 1		
5.7027	0.9307	0.9717	0.9966
4.0358	0.9595	0.6961	0.9982
1.9912	0.9882	0.4739	0.9991
1.4006	0.9936	0.3302	0.9994
	Run 2		
5.2391	0.9382	0.8263	0.9974
3.7351	0.9647	0.5982	0.9986
1.9250	0.9858	0.4317	0.9992
1.2951	0.9952		
	Run 3		
4.7608	0.9477	0.7672	0.9978
3.3389	0.9697	0.5410	0.9989
1.5766	0.9921	0.4013	0.9993
1.1193	0.9958		
	Temp, 353.15 K, Run 1		
5.7162	0.9445	0.8914	0.9985
4.0750	0.9696	0.6905	0.9990
2.0050	0.9926	0.4945	0.9993
1.3962	0.9963	0.3514	0.9996
	Run 2		
5.2624	0.9516	0.9180	0.9984
3.7390	0.9745	0.6450	0.9991
1.8611	0.9936	0.4548	0.9994
1.3113	0.9968	0.3189	0.9997
	Run 3		
4.6103	0.9614	0.6307	0.9993
3.0670	0.9817	0.4468	0.9995
1.5394	0.9950	0.3153	0.9997
1.0902	0.9978		
	Temp, 373.15 K, Run 1		
6.0344	0.9484	1.0668	0.9986
4.2877	0.9697	0.7060	0.9994
2.1190	0.9940	0.5197	0.9997
1.5070	0.9970	0.4156	0.9998
	Run 2		
5.6251	0.9541	0.9737	0.9988
3.9934	0.9766	0.6822	0.9995
1.9891	0.9948	0.4774	0.9998
1.3978	0.9974	0.3350	0.9999
	Run 3		
5.2994	0.9585	0.9189	0.9990
3.7673	0.9772	0.6430	0.9996
1.8720	0.9955	0.4505	0.9998
1.3181	0.9978	0.3141	0.9999

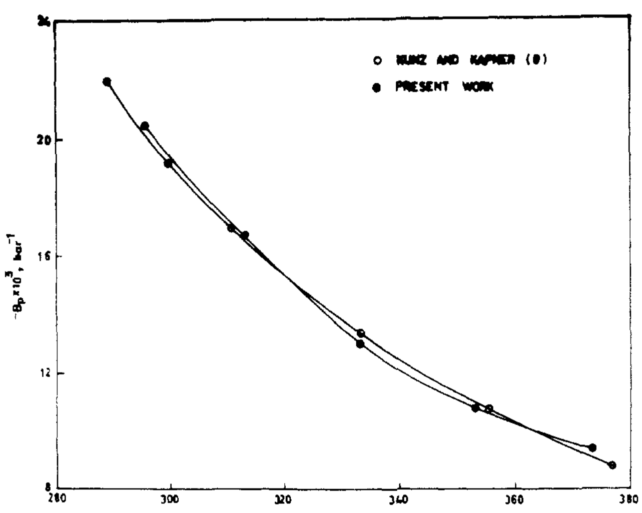

Figure 1. Second virial coefficients for R-12 gas.

Glossary

B_p second virial coefficient, bar^{-1}
n number of moles
P pressure, bar
R universal gas constant, bar m^3/(g-mol K)
T temperature, K
V Volume, m^3
Z compression factor, $PV/(nRT)$

Table II. Second Virial Coefficients of R-12

temp, K	$-10^3 B_p$, bar^{-1}	temp, K	$-10^3 B_p$, bar^{-1}
298.15	20.41	353.15	10.78
313.15	16.69	373.15	9.42
333.15	13.05		

Literature Cited

(1) Prasad, M. Ph.D. Dissertation, Indian Institute of Technology, Kanpur, India, 1976.
(2) Prasad, M.; Kudchadker, A. P. *J. Chem. Eng. Data* **1978**, *23*, 190.
(3) Buffington, R. M.; Gilkey, W. K. *Ind. Eng. Chem.* **1931**, *23*, 254.
(4) E. I. du Pont de Nemours and Co. "Thermodynamic Properties of Freon-12 Refrigerant (Dichlorodifluoromethane)", Bull. T 12, 1956.
(5) Kells, L. F.; Orfeo, S. R.; Mears, W. H. *Refrig. Eng.* **1955**, *63*, 46.
(6) McHarness, R. C.; Eiseman, B. J.; Martin, J. J. *Refrig. Eng.* **1955**, *63*, 32.
(7) Michels, A.; Wassenaar, T.; Wolkers, G. J.; Prins, C.; Klundert, L. v. d. *J. Chem. Eng. Data* **1966**, *11*, 449.
(8) Kunz, R. G.; Kapner, R. S. *J. Chem. Eng. Data* **1969**, *14*, 190.
(9) Burnett, E. S. *J. Appl. Mech.* **1936**, *58*, A136.
(10) Silberberg, I. H.; Kobe, K. A.; McKetta, J. J. *J. Chem. Eng. Data* **1959**, *4*, 314.
(11) Eubank, P. T.; Kerns, W. J. *AIChE J.* **1973**, *19*, 711.

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