EVALUATION OF P-V-T PROPERTIES DATA

The Most Probable Values of Compressibility Factor of

Gaseous Ethane and Ethene

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The critical evaluations of the P-V-T data of gaseous ethane and ethene have been carried out based upon the experimental data available in literatures. All of the experimental measurements under high pressure were evaluated in view of their reliability and the data were correlated with temperature and pressure. The most probable values and the reference values of the compressibility factor of gaseous ethane and ethene are presented in the form of numerical tables covering the range of temperature from 273.15 to 498.15 K and that of pressure up to 303.98×10^5 Pa for ethane, and from 273.15 to 423.15 K and up to 810.60×10^5 Pa for ethene. The estimated uncertainty of the tabulated values is also presented in the tables.

Introduction

The evaluation of P-V-T properties of gases at high presure has been made as a part of program of "High Pressure Data Center of Japen" organized in the Society of Material Science, Japan, with the sponsorship of the Agency of Science and Technology. In the program, the work for the evaluation of P-V-T properties of gaseous methane had already been made and reported previously in this journal[1]. Next to it, this work for gaseous ethane and ethene has also been performed in a similar manner to the case of methane. The following members of the Committee and researchers attended for the discussion on the present work:

J. Osugi, Y. Takezaki   (Kyoto Univ.);
I. Tanishita   (Nippon Univ.);
H. Iwasaki, S. Takahashi (Tohaku Univ.);
T. Makita, Y. Tanaka   (Kobe Univ.):
A. Nagashima   (Keio Univ.),

to whom the authors wish to express sincere gratitude for their valuable suggestions and disscussions.

1) J. Osugi, Y. Takezaki and T. Makita, This Journal, 41, 60 (1971)

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Survey and evaluation of *P-V-T* data

There exist seven and eleven different measurements an the *P-V-T* relations of gaseous ethane and ethene, respectively, under high pressures as listed below :

Ethane

A. Michels, W. Van Straaten and J. Dawson	(1954) [2]
A. Michels, snd G. W. Nederbragt	(1939) [3]
J. A. Beattie, G. J. Su and G. L. Simard	(1939) [4]
J. A. Beattie, C. Hadlock and N. Poffenberger	(1935) [5]
H. H. Reamer, R. H. Olds, B. H. Sage and W. N. Lacey	(1944) [6]
B. H. Sage, D. C. Webster and W. N. Lacey	(1937) [7]
V. M. Miniovich and G. A. Sorina	(1971) [8]

Ethene

A. Michels and M. Geldermans	(1942) [9]
A. Michels, J. De Gruyter and F. Niesen	(1936) [10]
A. Sass, B. F. Dodge and R. H. Bretton	(1967) [11]
W. Thomas and M. Zander	(1966) [12]
P. S. Ku and B. F. Dodge	(1967) [13]
R. J. Walters, J. H. Tracht, E. B. Weinberger and	
J. K. Rodgers	(1954) [14]
R. C. Lee and W. C. Edmister	(1970) [15]
H. G. McMath and W. C. Edmister	(1969) [16]
V. H. Danneel and H. Stoltzenberg	(1929) [17]
C. A. Crommelin and H. G. Watts	(1927) [18]

2) A. Michels, W. Van Straaten and J. Dawson, *Physica*, **20**, 17 (1954)

3) A. Michels and G. W. Nederbragt, *ibid.*, **6**, 656 (1939)

4) J. A. Beattie, G. J. Su and G. L. Simard, *J. Am. Chem. Soc.*, **61**, 926 (1939)

5) J. A. Beattie, C. Hadlock and N. Poffenberger. *J. Chem. Phys.*, **3**. 93 (1935)

6) H. H. Reamer, R. H. Olds, B. H. Sage and W. N. Lacey, *Ind. Eng. Chem.*, **36**, 956 (1944)

7) B. H. Sage, D. C. Webster and W. N. Lacey, *ibid.*, **29**, 658 (1937)

8) V. M. Miniovich and G. A. Sorina, *Zh. Fiz. Khim.*, **1971**, **45** (3) 552 (1971)

9) A. Michels and M. Geldermans, *Physica*, **9**, 967 (1942)

10) A, Michels, J. De Gruyter and F. Niesen, *ibid.*, **3**, 346 (1936)

11) A. Sass, B. F. Dodge and R. H. Bretton, *J. Chem. Eng. Data*, **12**, 168 (1967)

12) W. Thomas and M. Zander, *Z. angew. Phys.*, **20**, 417 (1966)

13) P. S. Ku and B. F. Dodge, *J. Chem. Eng. Data*, **12**, 158 (1967)

14) R. J. Walters, J. H. Tracht, E. B. Weinberger and J. K. Rodgers, *Chem. Eng. Progress*, **50**. 511 (1954)

15) R. C. Lee and W. C. Edmister, *A. I. Ch. E. Journal*, **16**, 1047 (1970)

16) H. G. McMath and W. C. Edmister, *ibid.*, **15**, 370 (1969)

17) V. H. Danneel and H. Stoltzenberg, *Z. angew. Chem.*, **42**, 1121 (1929)

18) C. A. Crommelin and H. G. Watts, *Comm. Phys. Lab. Leiden*, No. 189–C (1927)

I. Masson and L. G. F. Dolley   (1923)[19]

The original papers were carefully read through and examined from viewpoint of the reliability of the reported data by the same operations as in the previous work for gaseous methane[1].

The final evaluation was performed by the Committee members and several researchers in this field as described above. As the results for ethane, the set of data by Michels et al.[2] was considered to be the most reliable and given the highest weight. The weight second to the above were given to other four sets of data[3~6]. The weight third to the above was given to the set of data[7] and no weight was given to the remainder[8] in which the data were reported only in the limited range around the critical point. For ethene, the set of data by Michels et al.[9] was considered to be the most reliable and given the highest weight. The weight second to the above were given to other two sets of data[11,12]. The weight third to the above was given to the set of data[13]. The weights fourth to the above were given to three sets of data[14~16]. No weight was given to three earlier data[17~19]. It was also given to the early data by Michels et al.[10] because they were represented in the set of their new data[9] with some corrections.

Methods and results of correlation

The P-V-T properties of gases in original papers were expressed in various forms such as compressibility factor Z, specific volume V, PV in Amagat unit and so on, with various units of pressure, temperature, volume and mass. At first, they were reduced to the common expression Z with the SI units of pressure and temperature:

compressibility factor, $Z = PV/RT$,

pressure, P, in 10^5 Pa ($= 1$ bar $= 0.986923$ atm) and in atm,

temperature, T, in K,

specific volume, V, in cm³/mole.

In these processes, the atomic weights recommended by IUPAC (1969)[20] were adopted as follows: $C = 12.011 \pm 0.001$ and $H = 1.0080 \pm 0.0003$. For the universal gas constant, the numerical value recommended by IUPAC (the 23rd Conference)[21~23] was adopted:

$R = 8.31433 \pm 0.00044$ (J/K·mole)

$= 82.056 \pm 0.004$ (cm³·atm/K·mole).

The maximum relative uncertainties of Z due to the uncertainties of atomic weights, which amount to 1.2×10^{-4} for ethane and ethene, are not significantly lower than the experimental errors in the precisest measurements. The relative uncertainty of Z due to the uncertainties of R amounts to

19) I. Masson and L. G. F. Dolley, *Proc. Roy. Soc.*, **A103**, 524 (1923)

20) Commission on Atomic Weights, *Pure and Appl. Chem.*, **21**, 95 (1970)

21) M. L. McGlashan, *ibid.*, **21**, 37 (1970)

22) F. R. Rossini, *ibid.*, **9**, 453 (1964)

23) Thermodynamics Research Center Project, "Selected Values of Properties of Chemical Compounds", Texas A and M Univ., pp. 11~20 (1966)

5.3×10^{-5}, which can be neglected even for the precisest measurements.

It is difficult to estimate the relative uncertainty of Z due to the impurities in the sample gases. However the majority of the samples were pure above 99.9%, and it was regarded that the most abundant impurities were similar hydrocarbons having the like values of Z to the value of ethane or ethene. No correction was made in the calculation of Z and the considerations on purity were taken into the evaluation together with other factors.

In the present correlations of the compressiblitity factors of ethane and of ethene at high pressure, the so-called grid-point method was employed predominantly as follows.

It is the same method as used in the early correlation of the *P-V-T* properties of methane. That is, the values of Z at common grid-points of temperatures and pressures were obtained from the original data reported in respective works. When the data reported are not at one of the common grid-points specified, the interpolation procedures were carried out along an isotherm or an isobar on a digital computer using the least squares method. The precaution was paied for this procedure in order to keep on the experimental accuracy in each original data. Then the mean values at each grid-point were calculated with the weights determined by the critical evaluation in the preceding section. The standard deviations σ were also calculated by the following expression:

$$\sigma = \sqrt{\frac{\Sigma[\omega_i(Z_i - \bar{Z})^2]}{\Sigma\omega_i(n-1)}},$$

where $\omega_i =$ the weight given,

$Z_i =$ the compressibility factor in the original work,

$\bar{Z} =$ the tabulated compressibility factor value,

$n =$ the number of data sources.

The weighted mean compressibility factor values obtained for ethane are shown in Table 1. The values surrounded by the broken line in the table are "the most probable values of Z" recommended in the Committee because they were obtained by treating the original data in the region containing the most reliable one. The standard deviations to them are also given in the parentheses. The values outside of the broken line in the table are relatively less reliable than the above, because they were obtained only from the data given by low weights. However, they are useful as the reference values, because there is no data more reliable in the present than the data used.

Similarly, as the most probable Z values recommended in the Committee, the weighted mean values obtained for ethene are shown together with the standard deviations in the range surrounded by the broken line in Table 2.

For the evaluation of the compressibility factor of ethane and that of ethene, another method was also tried as follows. At first, sets of the original values of Z with the weights given by the Committee were developed to the power series of density along respective experimental isotherms up to 0.3 g/cm³ for ethane and up to 0.45 g/cm³ for ethene. Then the values of Z at round densities calculated by the above procedures were developed to the power series of temperature along each isochore with the reasonable weights given to the values of Z on each isotherm, and the values of Z were calculated at round densities and at the tabulated temperatures. Using these values, the correlations for the isotherms were obtained in the power series of density. Finally, the correlated values of Z at the grid-

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Table 1   Most probable values and additional recommended values for the compressibility factor of ethane

Pressure		Temperature K (°C)									
10^5 Pa	(atm)	273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)
1.01325	(1)	0.99003 (0.00030)	0.99233 (0.00030)	0.99406 (0.00030)	0.99534 (0.00030)	0.99628 (0.00030)	0.99699 (0.00030)	0.99755 (0.00030)	0.99799 (0.00030)	0.99837 (0.00030)	0.99870 (0.00030)
10.132	(10)	0.8921	0.9199 (0.00012)	0.9386 (0.0009)	0.9523	0.9623	0.9697	0.9755	0.9800	0.9835	0.9864
20.265	(20)	0.7522 (0.00008)	0.8268 (0.0009)	0.8718 (0.0006)	0.9025 (0.0016)	0.9237 (0.0018)	0.9387 (0.0014)	0.9502 (0.0017)	0.9593	0.9662	0.9726
30.398	(30)		0.7125 (0.0015)	0.7976 (0.0008)	0.8491 (0.0010)	0.8836 (0.0011)	0.9084 (0.0007)	0.9269 (0.0010)	0.9400	0.9510	0.9603
40.530	(40)		0.5301 (0.0005)	0.7116 (0.0007)	0.7921 (0.0010)	0.8426 (0.0011)	0.8776 (0.0009)	0.9031 (0.0011)	0.9212	0.9363	0.9486
50.662	(50)			0.6069 (0.0005)	0.7312 (0.0009)	0.8006 (0.0012)	0.8463 (0.0007)	0.8793 (0.0011)	0.9033	0.9235	0.9382
60.795	(60)			0.4664 (0.0001)	0.6664 (0.0013)	0.7576 (0.0010)	0.8157 (0.0008)	0.8566 (0.0011)	0.8865	0.9097	0.9274
70.928	(70)				0.5976 (0.0006)	0.7146 (0.0008)	0.7859 (0.0011)	0.8347 (0.0014)	0.8697	0.8969	0.9178
81.060	(80)				0.5327 (0.0009)	0.6735 (0.0008)	0.7571 (0.0008)	0.8135 (0.0011)	0.8541	0.8853	0.9092
91.192	(90)				0.4849 (0.0004)	0.6365 (0.0008)	0.7306 (0.0008)	0.7942 (0.0012)	0.8396	0.8744	0.9003
101.32	(100)				0.4618 (0.0003)	0.6059 (0.0007)	0.7072 (0.0009)	0.7767 (0.0013)	0.8264	0.8643	0.8933
111.46	(110)					0.5839 (0.0007)	0.6873 (0.0009)	0.7614 (0.0013)	0.8151	0.8557	0.8866
121.59	(120)					0.5713 (0.0011)	0.6720 (0.0005)	0.7484 (0.0010)	0.8056	0.8485	0.8812
131.72	(130)					0.5668 (0.0008)	0.6612 (0.0004)	0.7391 (0.0008)	0.7972	0.8423	0.8766
141.86	(140)					0.5678 (0.0008)	0.6555 (0.0005)	0.7320 (0.0010)	0.7912	0.8377	0.8732
151.99	(150)					0.5738	0.6540 (0.0004)	0.7275 (0.0007)	0.7886	0.8342	0.8707
162.12	(160)					0.5835	0.6568 (0.0004)	0.7259 (0.0007)	0.7862	0.8322	0.8694
172.25	(170)					0.5957	0.6618 (0.0004)	0.7270 (0.0007)	0.7859	0.8335	0.8689
182.38	(180)					0.6104	0.6694	0.7302 (0.0004)	0.7869	0.8348	0.8729
192.52	(190)					0.6250	0.6789	0.7358 (0.0004)	0.7900	0.8366	0.8744
202.65	(200)						0.6900	0.7426 (0.0005)	0.7943	0.8396	0.8768
253.31	(250)							0.7954	0.8330	0.8693	0.9021
303.98									0.8895	0.9163	0.9425

( ) : Value of standard deviation

.... : The most probable values

points were calculated from these expressions by the Newton-Raphson method.

These correlated values were compared with those obtained by the grid-point method. Both the values were in good agreement within their standard deviations, but there are slight differences at 298.15 K and 40 atm for ethane, and at 298.15 K and 60 atm for ethene.

Compared with the grid-point method, the above method of correlation is useful for the ranges

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Table 2 Most probable values and additional recommended values for the compressibility factor of ethene

Pressure 10⁵ Pa	(atm)	Temperature K (°C) 273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)	398.15 (125)	423.15 (150)
1.01325	(1)	0.99242 (0.00030)	0.99443 (0.00030)	0.99571 (0.00030)	0.99661 (0.00030)	0.99727 (0.00030)	0.99779 (0.00030)	0.99822 (0.00030)
10.132	(10)	0.9215 (0.0015)	0.9406 (0.0011)	0.9546	0.9647	0.9720 (0.0001)	0.9778	0.9821
20.265	(20)	0.8284 (0.0005)	0.8749 (0.0006)	0.9066	0.9283	0.9438 (0.0002)	0.9555	0.9645
30.398	(30)		0.8030 (0.0010)	0.8552 (0.0009)	0.8904 (0.0004)	0.9153 (0.0002)	0.9334	0.9471
40.530	(40)		0.7195 (0.0018)	0.8013 (0.0013)	0.8518 (0.0005)	0.8866 (0.0002)	0.9114	0.9302
50.662	(50)		0.6190 (0.0003)	0.7436 (0.0014)	0.8124 (0.0006)	0.8579 (0.0003)	0.8898	0.9136
60.795	(60)		0.4844 (0.0003)	0.6818 (0.0016)	0.7723 (0.0009)	0.8295 (0.0004)	0.8688	0.8977
70.928	(70)		0.3409 (0.0003)	0.6171 (0.0019)	0.7323 (0.0011)	0.8017 (0.0006)	0.8484	0.8825
81.060	(80)		0.3170	0.5541 (0.0022)	0.6934 (0.0013)	0.7749 (0.0007)	0.8290	0.8682
91.192	(90)		0.3273	0.5017 (0.0023)	0.6572 (0.0015)	0.7497 (0.0007)	0.8108	0.8548
101.32	(100)		0.3451	0.4706 (0.0026)	0.6255 (0.0016)	0.7268 (0.0006)	0.7942	0.8425
111.46	(110)		0.3656	0.4605	0.6012 (0.0020)	0.7074 (0.0005)	0.7793	0.8314
121.59	(120)		0.3872	0.4622	0.5847 (0.0022)	0.6913 (0.0005)	0.7665	0.8218
131.72	(130)		0.4096	0.4711	0.5756 (0.0022)	0.6793 (0.0008)	0.7559	0.8136
141.86	(140)		0.4321	0.4841	0.5731 (0.0021)	0.6712 (0.0009)	0.7478	0.8070
151.99	(150)		0.4549	0.4996	0.5770	0.6668 (0.0010)	0.7421	0.8020
162.12	(160)		0.4777	0.5166	0.5839	0.6657 (0.0009)	0.7388	0.7987
172.25	(170)		0.5005	0.5346	0.5937	0.6679 (0.0009)	0.7379	0.7969
182.38	(180)		0.5233	0.5533	0.6055	0.6728 (0.0008)	0.7391	0.7969
192.52	(190)		0.5460	0.5724	0.6188	0.6801 (0.0010)	0.7422	0.7980
202.65	(200)		0.5687	0.5906 (0.0036)	0.6333	0.6889 (0.0008)	0.7470	0.8007
253.31	(250)		0.6798 (0.0033)	0.6898 (0.0039)	0.7149 (0.0013)	0.7494 (0.0008)	0.7896	0.8309
303.98	(300)		0.7889 (0.0040)	0.7888 (0.0044)	0.8027 (0.0018)	0.8233 (0.0008)	0.8503	0.8800
354.64	(350)		0.8962 (0.0049)	0.8880 (0.0055)	0.8916 (0.0025)	0.9027 (0.0009)	0.9189	0.9390
405.30	(400)		1.0015 (0.0058)	0.9851 (0.0063)	0.9802 (0.0029)	0.9839 (0.0009)	0.9913	1.0033
455.96	(450)		1.1046 (0.0064)	1.0813 (0.0071)	1.0684 (0.0032)	1.0653 (0.0006)	1.0652	1.0702
506.62	(500)		1.2063 (0.0070)	1.1758 (0.0077)	1.1560 (0.0034)			
607.95	(600)		1.4058 (0.0082)	1.3615 (0.0089)	1.3293 (0.0035)			
709.28	(700)		1.6008 (0.0088)	1.5430 (0.0099)	1.4995 (0.0037)			
810.60	(800)		1.7920 (0.0086)	1.7208 (0.0107)				

( ) : Value of standard deviation

[box] : The most probable values

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Table 3   The estimated uncertainties of compressibility factor of ethane

Pressure 10⁵Pa (atm)		Temperature K (℃)									
		273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)
1.01325	(1)	0.030%	0.030%	0.030%	0.030%	0.030%	0.030%	0.030%	0.030%	0.030%	0.030%
10.132	(10)	0.10	0.12	0.09	0.17	0.20	0.15	0.17	0.20	0.30	0.30
20.265	(20)	0.10	0.12	0.10	0.17	0.20	0.14	0.16	0.20	0.30	0.30
30.398	(30)		0.12	0.10	0.17	0.17	0.12	0.16	0.25	0.35	0.40
40.530	(40)		0.12	0.10	0.16	0.15	0.12	0.15	0.30	0.40	0.45
50.662	(50)			0.10	0.15	0.15	0.11	0.15	0.30	0.40	0.55
60.795	(60)			0.11	0.14	0.14	0.11	0.15	0.35	0.40	0.55
70.928	(70)				0.13	0.13	0.11	0.15	0.35	0.40	0.55
81.060	(80)				0.12	0.12	0.11	0.15	0.35	0.40	0.55
91.192	(90)				0.11	0.12	0.11	0.15	0.35	0.40	0.50
101.32	(100)				0.10	0.13	0.11	0.15	0.35	0.40	0.50
111.46	(110)					0.15	0.11	0.15	0.35	0.40	0.50
121.59	(120)					0.17	0.11	0.14	0.40	0.40	0.50
131.72	(130)					0.19	0.11	0.14	0.35	0.40	0.45
141.86	(140)					0.23	0.12	0.14	0.25	0.40	0.45
151.99	(150)					0.27	0.13	0.13	0.20	0.40	0.45
162.12	(160)					0.32	0.16	0.13	0.20	0.40	0.45
172.25	(170)					0.35	0.18	0.13	0.20	0.30	0.40
182.38	(180)					0.39	0.20	0.13	0.20	0.25	0.25
192.52	(190)					0.44	0.20	0.13	0.20	0.25	0.25
202.65	(200)						0.20	0.13	0.20	0.25	0.25
253.31	(250)							0.20	0.20	0.25	0.25
303.98	(300)								0.20	0.25	0.25
354.64	(350)								0.20		

in which the number of sources available is very restricted. In the case of ethene, there was only one source by Michels et al.[9] for the grid-points outside of the broken line in the table, and the mean values could not be obtained by the grid-point method. Thus, for these ranges, the values obtained by the correlation method are presented as the additional recommended values in Table 2. They are reconciled well with the adjacent values obtained by the grid-point method.

For ethane and ethene, the reliable values of Z at low pressure cannot be obtained by extrapolating the experimental values of Z at high pressures to the low pressures. The authors collected the reliable data of the experimental second and third virial coefficients, B_T and C_T, at low pressure for ethane[2, 24~30] and ethene[10~13, 18, 24, 25, 31~36]. Then using the expression : $Z=1+B_TP+C_TP^2$, each value of Z at 1 atm and at each experimental temperature was calculated. Their equally weighted mean values at the grid-points on 1 atm were calculated developing to the power series of temperature using the least square method. In Tables 1 and 2, those values are given as the recommended values of Z at the normal pressure, 1.01325×10^5 Pa ($=1$ atm), together with the standard deviations shown in the parentheses.

The original data sources are few at most of the grid-points for ethane and ethene. Thus the standard deviations calculated have little significance in regard to the statistical meaning and they showed some unreasonable irregularities at some local grid-points practically. From these viewpoints,

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Table 4   The estimated uncertainties of compressibility factor of ethene

Pressure		Temperature K (°C)						
10^5 Pa	(atm)	273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)	398.15 (125)	423.15 (150)
1.01325	(1)	0.030%	0.030%	0.030%	0.030%	0.030%	0.030%	0.030%
10.132	(10)	0.10	0.11	0.05	0.04	0.03	0.10	0.10
20.265	(20)	0.10	0.12	0.07	0.05	0.03	0.10	0.10
30.398	(30)		0.13	0.10	0.06	0.03	0.10	0.10
40.530	(40)		0.15	0.15	0.07	0.04	0.10	0.10
50.662	(50)		0.16	0.19	0.08	0.05	0.10	0.10
60.795	(60)		0.17	0.24	0.11	0.06	0.10	0.10
70.928	(70)		0.18	0.28	0.14	0.07	0.10	0.10
81.060	(80)		0.20	0.32	0.15	0.09	0.10	0.10
91.192	(90)		0.22	0.35	0.17	0.11	0.10	0.10
101.32	(100)		0.23	0.38	0.18	0.12	0.10	0.10
111.46	(110)		0.25	0.41	0.20	0.13	0.10	0.10
121.59	(120)		0.27	0.43	0.22	0.14	0.10	0.10
131.72	(130)		0.28	0.46	0.23	0.15	0.10	0.10
141.86	(140)		0.30	0.48	0.24	0.15	0.10	0.10
151.99	(150)		0.32	0.50	0.25	0.16	0.10	0.10
162.12	(160)		0.34	0.52	0.25	0.16	0.10	0.10
172.25	(170)		0.36	0.54	0.26	0.16	0.10	0.10
182.38	(180)		0.38	0.55	0.28	0.16	0.10	0.10
192.52	(190)		0.40	0.56	0.28	0.16	0.10	0.10
202.65	(200)		0.43	0.57	0.29	0.15	0.10	0.10
253.31	(250)		0.48	0.69	0.30	0.14	0.10	0.10
303.98	(300)		0.51	0.61	0.30	0.13	0.10	0.10
354.64	(350)		0.55	0.63	0.30	0.11	0.10	0.10
405.30	(400)		0.57	0.64	0.30	0.09	0.10	0.10
455.96	(450)		0.58	0.65	0.30	0.07	0.10	0.10
506.62	(500)		0.58	0.66	0.30			
607.95	(600)		0.58	0.65	0.28			
709.28	(700)		0.55	0.64	0.25			
810.60	(800)		0.48	0.62				

it is appropriate that the values determined as below are adopted for the uncertainty or the tolerance instead of the standard deviations.   The standard deviations were plotted in graph against pressures

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on each isotherm. The smoothed curves were drawn for each set of the standard deviations, with the precautions to keep in harmony with those of the adjacent isotherms and to exceed reasonably most of points of the standard deviations. The values read from the curves were recommended as the uncertainties of the tabulated values of Z. They are shown in Tables 3 and 4, in the form of the percentage deviation calculated by the following definition :

$$\text{uncertainty} = \frac{100 \times \bar{\sigma}}{\bar{Z}} ,$$

where $\bar{\sigma}$ is the smoothed standard deviation obtained by the method mentioned above and $\bar{Z}$ is the tabulated most reliable compressibility factor value.

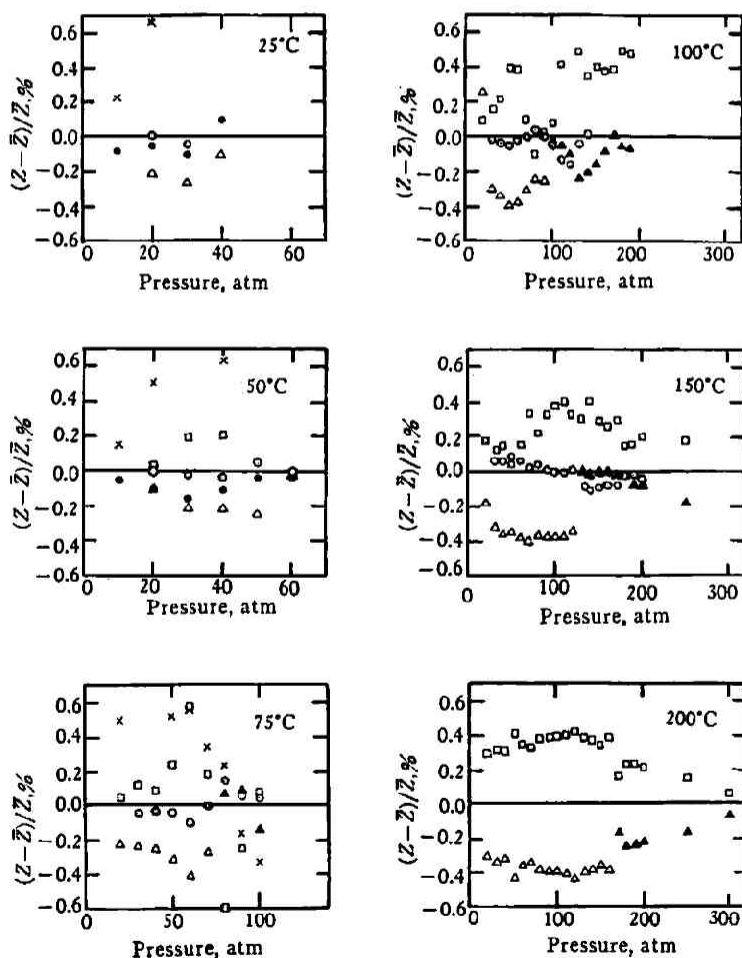The percentage deviations of the original data from the tabulated values were also calculated by :

Fig. 1 Percentage deviation diagrams for ethane

⊙: Ref 2),   ●: Ref 3),   ▲: Ref 4)

△: Ref 5),   □: Ref 6),   ×: Ref 7)

percentage deviation $= \dfrac{100(Z - \bar{Z})}{\bar{Z}}$,

where Z is the compressibility factor interpolated from the original measurements and $\bar{Z}$ is the tabulated most reliable compressibility factor value. Some of them are given graphically in Figs. 1 and 2.
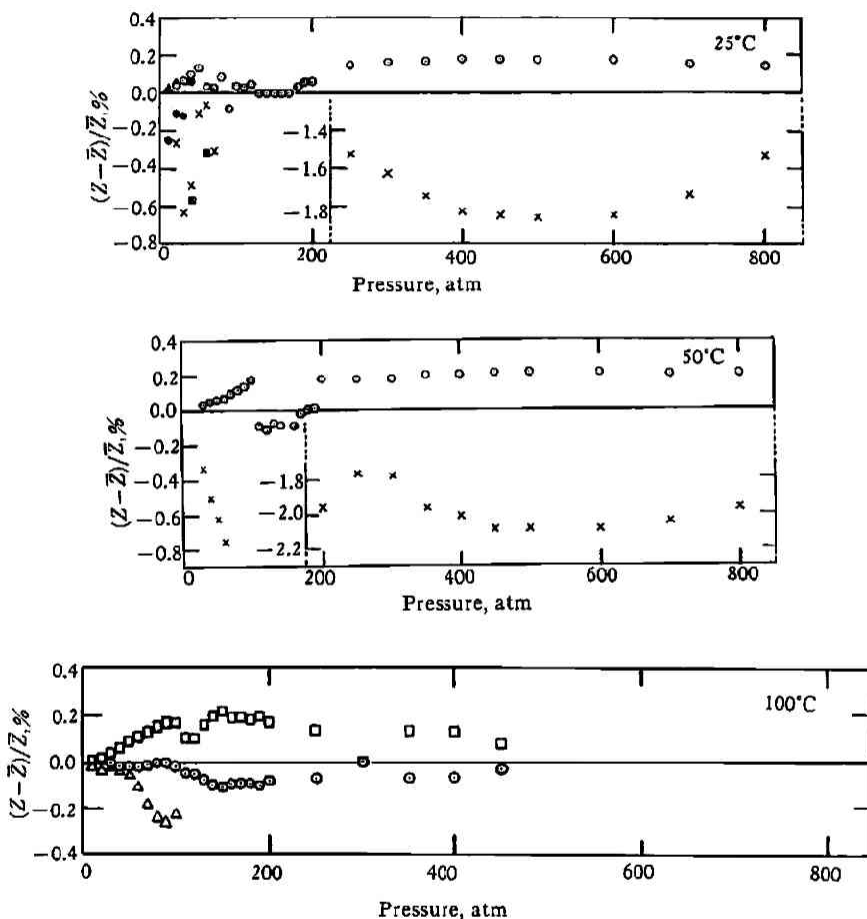
Fig. 2 Percentage deviation diagrams for ethene

⊙: Ref 9),   □: Ref 11),   ▲: Ref 12)
△: Ref 13),   ●: Ref 14),   ×: Ref 15)
■: Ref 16)

Acknowledgment