

THERMODYNAMIC PROPERTIES OF GASEOUS PROPANE AND PROPENE

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Based upon the most probable and additional recommended values with respect to the compressibility factor of propane and propene proposed by the High Pressure Data Center of Japan (HPDCJ), new thermodynamic formulations are devised for these substances in their gaseous phases covering the range of temperature from 273.15 K to 523.15 K and pressures up to 30 MPa for propane and also that of temperature from 248.15 K to 498.15 K and pressures up to 60 MPa for propene, respectively. Using the formulated equations of state, the basic correlating functions for these hydrocarbons are derived and then the essential thermodynamic properties such as molar volume, enthalpy, entropy and isobaric specific heat capacity can be calculated.

Introduction

According to the critical evaluation of the available P - V - T property data, the most probable and additional recommended compressibility factor values for propane and propene were proposed by Date and Iwasaki¹⁾ after the discussions at the HPDCJ organized in the Society of Materials Science, Japan, under the sponsorship of the Agency of Science and Technology. The covered range of the state parameters of this previous work was 248.15–548.15 K and pressures up to 30 MPa for propane, whereas 248.15–498.15 K and pressures up to 60 MPa for propene. As a next procedure of the program of the HPDCJ, new equations of state for both propane and propene are formulated based upon these most probable compressibility factor values for the purpose of calculating the P - V - T property values as well as other thermodynamic property values at respective thermodynamic states. In the present paper, these new equations of state which can cover the range of temperatures 273.15–523.15 K and of pressures up to 30 MPa for propane, and also that of temperature 248.15–498.15 K and of pressures up to 60 MPa for propene are described. Moreover, the numerical tables of the important derived thermodynamic property values are also presented for these two different hydrocarbons.

New Equations of State

The so-called skeleton table values of the compressibility factor for propane and propene are composed of the most probable and additional recommended values proposed by the HPDCJ and their covering ranges are shown in Figs. 1 and 2, respectively. It is needless to say that these skeleton table

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1) K. Date and H. Iwasaki, *This Journal*, **44**, 1 (1974)

2) A. P. Kudchadker, G. H. Alani and B. J. Zwolinski, *Chem. Rev.*, **68**, 659 (1968)

values are accompanied by the estimated uncertainties as in the previous skeleton tables for methane³⁾, ethane and ethene⁴⁾. In the present study, both of the most probable and additional recommended values were used as the basic data sets in devising the new equations of state, in addition to using the estimated uncertainties mentioned above as the criteria for judging the devised equations.

As shown in Fig. 1, the skeleton table of compressibility factor for propane includes those even in the liquid phase and therefore those data below 373.15 K were excluded to be covered by the present formulation beforehand. It is also noteworthy that the present equations of state have to be formulated as a function of density and temperature, since they must cover such wider ranges of the state para-

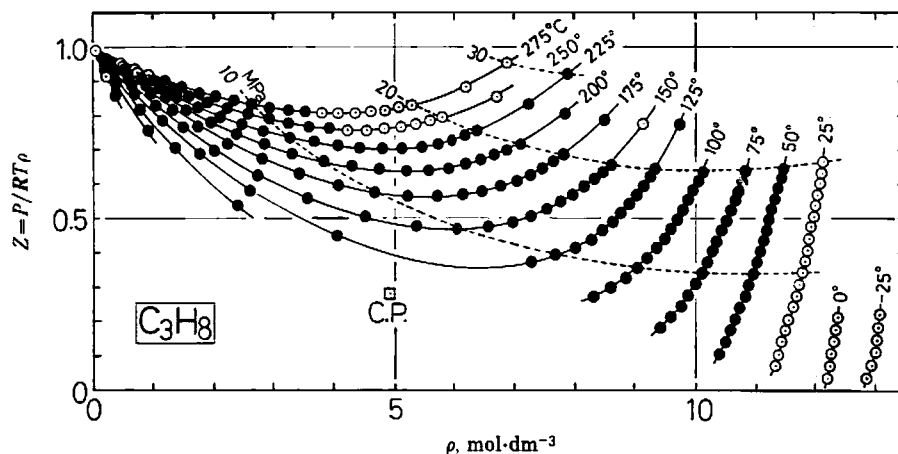


Fig. 1 The most probable and additional recommended compressibility factor values for propane

- most probable values
- additional recommended values
- critical point (369.82 K, 4.250 MPa, 4.92 mol·dm⁻³)²⁾

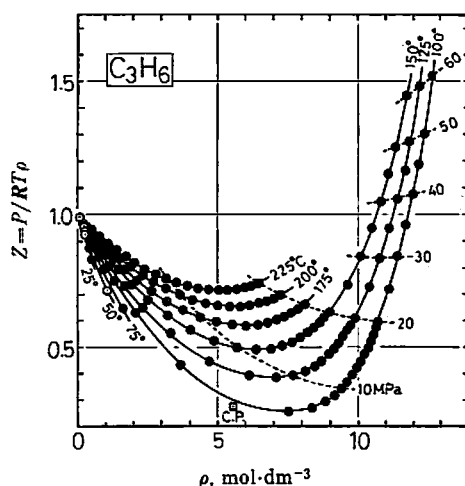


Fig. 2 The most probable and additional recommended compressibility factor values for propene

- most probable values
- additional recommended values
- critical point (365.0 K, 4.62 MPa, 5.54 mol·dm⁻³)²⁾

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

4) K. Date, K. Watanabe and M. Uematsu, *ibid.*, **43**, 92 (1973)

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meters as shown in Figs. 1 and 2. Although it is well known that the Benedict-Webb-Rubin (BWR) equation of state may correlate the P - V - T properties of simple hydrocarbons, it was experienced in

Table 1 Numerical constants in Eqs. (1) and (2) for propane and propene

	Propane	Propene		Propane	Propene
a_1	$-4.090\ 9899 \times 10^2$	$1.770\ 6253 \times 10^3$	a_{17}	0	$4.937\ 6880 \times 10^{16}$
a_2	$6.221\ 3928 \times 10^5$	$-1.407\ 2709 \times 10^6$	a_{18}	0	$-1.821\ 7334 \times 10^{19}$
a_3	$-4.269\ 9835 \times 10^{11}$	$2.815\ 5700 \times 10^{10}$	a_{19}	$-2.782\ 3613 \times 10^{19}$	$2.140\ 9060 \times 10^{21}$
a_4	$6.987\ 0832 \times 10^{16}$	$-1.982\ 3817 \times 10^{15}$	a_{20}	$-1.848\ 2512 \times 10^{14}$	$2.560\ 2341 \times 10^{15}$
a_5	$-6.741\ 6069 \times 10^{21}$	$-8.976\ 3010 \times 10^{19}$	a_{21}	$8.302\ 6578 \times 10^{16}$	$-2.976\ 8160 \times 10^{18}$
a_6	$2.827\ 2012 \times 10^{26}$	$5.317\ 8698 \times 10^{24}$	a_{22}	0	$1.138\ 5003 \times 10^{21}$
a_7	$-2.187\ 7931 \times 10^{35}$	0	a_{23}	0	$-1.417\ 9285 \times 10^{23}$
a_8	$-1.294\ 8332 \times 10^5$	$-7.567\ 4088 \times 10^5$	a_{24}	$3.341\ 9911 \times 10^5$	0
a_9	$3.186\ 4286 \times 10^8$	$7.109\ 3220 \times 10^8$	a_{25}	$-4.064\ 7594 \times 10^8$	0
a_{10}	0	$-1.505\ 5735 \times 10^{11}$	a_{26}	$6.923\ 3929 \times 10^{13}$	$4.048\ 8404 \times 10^{12}$
a_{11}	$-4.590\ 3560 \times 10^{13}$	$-7.422\ 0764 \times 10^{11}$	a_{27}	$-1.458\ 5349 \times 10^{18}$	0
a_{12}	$1.728\ 3452 \times 10^7$	$2.325\ 5824 \times 10^8$	γ	$1.944\ 4748 \times 10^4$	$2.479\ 0640 \times 10^4$
a_{13}	$2.448\ 3052 \times 10^{10}$	$-1.617\ 1961 \times 10^{11}$	c_1	$3.663\ 65 \times 10^0$	$3.209\ 14 \times 10^1$
a_{14}	$1.020\ 5948 \times 10^{15}$	$1.150\ 2383 \times 10^{16}$	c_2	$2.547\ 41 \times 10^{-1}$	$4.724\ 83 \times 10^{-2}$
a_{15}	$3.160\ 9572 \times 10^{22}$	$-4.218\ 4990 \times 10^{22}$	c_3	$-5.758\ 13 \times 10^{-5}$	$2.714\ 90 \times 10^{-4}$
a_{16}	$1.455\ 4779 \times 10^{12}$	$-4.297\ 6459 \times 10^{13}$	c_4	$-3.047\ 05 \times 10^{-8}$	$-2.328\ 43 \times 10^{-7}$

Table 2 Average deviations of the compressibility factor values for propane and propene from Eq. (1)

	Available data sources	Number of data points compared	Average deviation* (%)
Propane	Skeleton table values ¹⁾	178	0.092
	Sage <i>et al.</i> (1934) ¹⁰⁾	56	0.944
	Beattie <i>et al.</i> (1937) ¹¹⁾	87	0.163
	Deschner <i>et al.</i> (1940) ¹²⁾	147	0.700
	Lu (1940) ¹³⁾	—	—**
	Reamer <i>et al.</i> (1949) ¹⁴⁾	164	0.133
	Cherney <i>et al.</i> (1946) ¹⁵⁾	15	0.359
Propene	Skeleton table values ¹⁾	167	0.057
	Farrington <i>et al.</i> (1949) ¹⁶⁾	194	0.121
	Marchman <i>et al.</i> (1949) ¹⁷⁾	202	0.118
	Michels <i>et al.</i> (1953) ¹⁸⁾	190	0.054

* Calculated by the expression given below:

$$\sigma(\%) = \frac{\sum |(Z_{\text{exp}} - Z_{\text{cal}})|}{n} \times 100,$$

where Z_{exp} = reported compressibility factor values,

Z_{cal} = calculated values by Eq. (1),

n = number of data points compared.

** Reported data by Lu are in liquid phases where the present formulation is not effective.

Table 3-1 Calculated values of compressibility factor Z of gaseous propane and their comparison with the skeleton table values

Pressure MPa	Temperature K (°C)				
	273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)
0.1	0.97913	0.98440	0.98787	0.99028	0.99204
	0.97948	0.98392	0.98737	0.99000	0.99198
	-0.035/0.040	0.049/0.040	0.051/0.040	0.028/0.040	0.006/0.040
0.5		0.9119	0.9348	0.9487	0.9591
		0.91433	0.93403	0.94851	0.95911
		-0.265/0.35	0.082/0.25	0.020/0.20	-0.001/0.15
1			0.8599	0.8927	0.9140
			0.85913	0.89262	0.91599
			0.089/0.25	0.009/0.30	-0.217/0.35
2				0.7565	0.8194
				0.75956	0.82064
				-0.403/0.50	-0.151/0.50
3	1st line : skeleton table value, Z_{ST}				0.7057
	2nd line : calculated value, Z_{cal}				0.70516
	3rd line : deviation(%) / uncertainty(%)				0.077/0.30
4	deviation(%) = $[(Z_{ST} - Z_{cal}) / Z_{cal}] \times 100$				0.5380
					0.53599
					0.375/0.30

our previous work⁵⁾ that several additional terms were required to the original BWR equation in order to cover wider range of the present interest.

Hence, after several possible additional terms had been tested taking into consideration the possibility for obtaining a common functional form for both substances, the following functional form which was developed from the original BWR equation was adopted for the present purpose:

$$\begin{aligned}
 P = RT\rho &+ (a_1T + a_2 + a_3/T^2 + a_4/T^4 + a_5/T^6 + a_6/T^8 + a_7/T^{12})\rho^2 \\
 &+ (a_8T + a_9 + a_{10}/T + a_{11}/T^2)\rho^3 + (a_{12}T + a_{13} + a_{14}/T^2 + a_{15}/T^5)\rho^4 \\
 &+ (a_{16} + a_{17}/T + a_{18}/T^2 + a_{19}/T^3)\rho^5 + (a_{20} + a_{21}/T + a_{22}/T^2 + a_{23}/T^3)\rho^6 \\
 &+ (a_{24}T + a_{25} + a_{26}/T^2 + a_{27}/T^4)\rho^3(1 + \gamma\rho^2) \exp(-\gamma\rho^2), \quad (1)
 \end{aligned}$$

where P =pressure in MPa, T =temperature in K, $T=t+273.15$, t =temperature in °C on IPTS-68, ρ =molar density in mol·cm⁻³, R =molar gas constant in J·K⁻¹mol⁻¹, and $a_1, a_2, \dots, a_{27}, \gamma$ =numerical constants.

The following values were adopted as the atomic weights recommended by IUPAC⁶⁾ as well as the molar gas constant recommended by CODATA⁷⁾:

$$C = 12.011 \pm 0.001,$$

5) M. Uematsu, S. Saegusa, K. Watanabe and I. Tanishita, *This Journal*, **45**, 53 (1975)

6) *Pure and Appl. Chem.*, **37**, 589 (1974)

7) *CODATA Bull.*, No. 11 (1973)

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Table 3-2 (continued)

Pressure MPa	Temperature K (°C)					
	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)	523.15 (250)
0.1	0.99339 0.99348 -0.009/0.040	0.99448 0.99464 -0.016/0.040	0.99539 0.99555 -0.016/0.040	0.99620 0.99629 -0.009/0.040	0.99691 0.99688 0.003/0.040	0.99757 0.99737 0.020/0.040
0.5	0.9672 0.96699 0.022/0.10	0.9727 0.97300 -0.031/0.10	0.9773 0.97770 -0.041/0.10	0.9813 0.98144 -0.014/0.10	0.9845 0.98445 0.005/0.10	0.9867 0.98692 -0.022/0.15
1	0.9328 0.93286 -0.007/0.10	0.9451 0.94549 -0.041/0.10	0.9550 0.95521 -0.022/0.10	0.9629 0.96288 0.002/0.10	0.9693 0.96903 0.028/0.10	0.9713 0.97402 -0.279/0.15
2	0.8623 0.86049 0.211/0.10	0.8893 0.88867 0.071/0.10	0.9096 0.90965 -0.006/0.10	0.9257 0.92582 -0.013/0.15	0.9389 0.93858 0.034/0.15	0.9484 0.94881 -0.043/0.15
3	0.7826 0.78069 0.244/0.10	0.8299 0.82902 0.106/0.10	0.8629 0.86327 -0.043/0.10	0.8891 0.88891 0.022/0.15	0.9097 0.90876 0.104/0.15	0.9240 0.92447 -0.051/0.15
4	0.6894 0.68958 -0.026/0.15	0.7663 0.76589 0.054/0.10	0.8161 0.81607 0.004/0.10	0.8527 0.85227 0.051/0.15	0.8811 0.87970 0.159/0.15	0.9015 0.90111 0.044/0.15
5	0.5799 0.57959 0.054/0.30	0.6973 0.69864 -0.192/0.10	0.7680 0.76817 -0.022/0.10	0.8160 0.81611 -0.014/0.15	0.8521 0.85157 0.062/0.15	0.8784 0.87884 -0.050/0.15
6	0.4474 0.44589 0.338/0.30	0.6258 0.62763 -0.292/0.20	0.7198 0.72010 -0.042/0.15	0.7804 0.78079 -0.050/0.15	0.8244 0.82460 -0.024/0.15	0.8567 0.85780 -0.129/0.20
7		0.5583 0.55763 0.120/0.50	0.6726 0.67320 -0.089/0.20	0.7467 0.74690 -0.027/0.15	0.7985 0.79909 -0.074/0.15	0.8375 0.83817 -0.080/0.20
8		0.5028 0.50290 -0.021/0.50	0.6284 0.63026 -0.295/0.40	0.7160 0.71540 0.084/0.15	0.7753 0.77547 -0.021/0.15	0.8206 0.82015 0.055/0.20
9	0.3726 0.37102 0.426/0.40	0.4753 0.47533 -0.006/0.50	0.5945 0.59557 -0.180/0.25	0.6885 0.68762 0.128/0.10	0.7542 0.75425 -0.007/0.20	0.8048 0.80398 0.103/0.25
10	0.3920 0.39113 0.222/0.60	0.4691 0.46953 -0.092/0.45	0.5740 0.57278 0.213/0.15	0.6661 0.66513 0.145/0.10	0.7364 0.73607 0.044/0.15	0.7903 0.78992 0.048/0.25
11	0.4138 0.41422 -0.100/0.45	0.4747 0.47613 -0.300/0.25	0.5646 0.56224 0.421/0.15	0.6515 0.64920 0.355/0.10	0.7211 0.72156 -0.063/0.15	0.7783 0.77826 0.005/0.15
12	0.4372 0.43874 -0.351/0.30	0.4885 0.48944 -0.191/0.20	0.5632 0.56153 0.297/0.20	0.6424 0.64022 0.340/0.25	0.7107 0.71117 -0.066/0.15	0.7689 0.76926 -0.046/0.15
13	0.4635 0.46403 -0.113/0.30	0.5064 0.50654 -0.028/0.30	0.5670 0.56775 -0.131/0.20	0.6378 0.63769 0.018/0.35	0.7046 0.70511 -0.072/0.25	0.7625 0.76308 -0.077/0.20
14	0.4893 0.48972 -0.086/0.30	0.5272 0.52592 0.244/0.20	0.5785 0.57861 -0.020/0.15	0.6394 0.64050 -0.171/0.20	0.7023 0.70323 -0.133/0.15	0.7596 0.75981 -0.027/0.20

Table 3-3 (continued)

Pressure	Temperature K (°C)					
MPa	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)	523.15 (250)
15	0.5157	0.5482	0.5924	0.6462	0.7036	0.7588
	0.51563	0.54671	0.59260	0.64748	0.70514	0.75936
	0.013/0.30	0.273/0.20	-0.034/0.10	-0.198/0.25	-0.218/0.15	-0.074/0.20
16	0.5417	0.5692	0.6085	0.6573	0.7089	0.7607
	0.54165	0.56841	0.60872	0.65760	0.71027	0.76157
	0.009/0.20	0.138/0.25	-0.037/0.10	-0.046/0.30	-0.193/0.20	-0.114/0.20
17	0.5680	0.5909	0.6265	0.6702	0.7174	0.7654
	0.56770	0.59072	0.62632	0.67006	0.71868	0.76617
	0.053/0.20	0.030/0.30	0.029/0.10	0.021/0.10	-0.094/0.20	-0.100/0.20
18	0.5942	0.6131	0.6451	0.6844	0.7286	0.7726
	0.59374	0.61344	0.64497	0.68426	0.72803	0.77286
	0.078/0.20	-0.055/0.35	0.021/0.10	0.020/0.25	0.078/0.15	-0.034/0.20
19	0.6205	0.6355	0.6641	0.6992	0.7406	0.7820
	0.61974	0.63642	0.66437	0.69977	0.73970	0.78134
	0.123/0.30	-0.145/0.35	-0.040/0.10	-0.081/0.20	0.121/0.20	0.084/0.20
20	0.6466	0.6586	0.6843	0.7158	0.7538	0.7931
	0.64568	0.65959	0.68431	0.71626	0.75273	0.79133
	0.143/0.45	-0.150/0.35	-0.002/0.10	-0.064/0.20	0.142/0.20	0.224/0.20
25	0.7730	0.7772	0.7878	0.8072	0.8309	0.8558
	0.77417	0.77638	0.78833	0.80704	0.83022	0.85627
	-0.152/0.50	0.106/0.40	-0.067/0.25	0.020/0.20	0.082/0.20	-0.055/0.20
30	[] : the most probable values				0.9179	
	1st line : skeleton table value, Z_{ST}				0.91728	
	2nd line : calculated value, Z_{cal}				0.068/0.10	
3rd line : deviation(%) / uncertainty(%); deviation(%) = $[(Z_{ST} - Z_{cal}) / Z_{cal}] \times 100$						

$$H = 1.0079 \pm 0.0001,$$

$$R = 8.31441 \pm 0.00026 \text{ J} \cdot \text{K}^{-1} \text{ mol}^{-1}.$$

In the procedure of determining the numerical constants in Eq. (1), the skeleton table values were introduced as a set of input data into a least-square processing and the characteristic behavior of the computed isobaric specific heat capacity values were also carefully examined. Especially, the reported experimental values by Bier *et al.*⁸⁾ for propene in the range of temperature 298.15 K–473.15 K and pressures up to 12 MPa were taken into consideration for the present purpose. As a result of these procedures, the numerical constants for both propane and propene in Eq. (1) were fixed on as listed in Table 1.

In case of computing the isobaric specific heat capacity, the following correlations for the isobaric specific heat capacity at the ideal gas state, C_p^0 , devised by Makita⁹⁾ were used:

$$C_p^0 = c_1 + c_2 T + c_3 T^2 + c_4 T^3. \quad (2)$$

The numerical constants which appeared in Eq. (2) are also tabulated for both propane and propene

8) K. Bier, G. Ernst, J. Kunze and G. Maurer, *J. Chem. Thermodynamics*, 6, 1039 (1974)

9) T. Makita, private communication to the present author

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Table 4-1 Calculated values of compressibility factor Z of gaseous propane and their comparison with the skeleton table values

Pressure MPa	Temperature T (°C)											
	248.15 (-25)	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)	
0.1	0.97481 0.97471 0.010/0.020	0.98151 0.98129 0.022/0.020	0.98602 0.98588 0.014/0.020	0.98919 0.98907 0.012/0.020	0.99148 0.99136 0.012/0.020	0.99317 0.99305 0.012/0.020	0.99444 0.99435 0.009/0.020	0.99543 0.99536 0.007/0.020	0.99523 0.99510 0.006/0.020	0.99689 0.99684 0.005/0.020	0.99746 0.99739 0.007/0.020	
0.5	0.9246 0.92512 -0.056/0.10	0.9450 0.94311 0.200/0.10	0.9558 0.95558 0.369/0.10	0.9591 0.95907 0.012/0.020	0.9640 0.96459 -0.061/0.10	0.9640 0.96459 -0.061/0.10	0.9714 0.97137 0.003/0.10	0.9767 0.97662 0.009/0.10	0.9812 0.98078 0.043/0.10	0.9847 0.98415 0.056/0.10	0.9870 0.98692 0.008/0.10	
1	0.8354 0.83579 -0.047/0.10	0.8792 0.87937 -0.019/0.10	0.9073 0.90765 -0.039/0.10	0.9274 0.92735 0.006/0.10	0.9418 0.94177 0.003/0.10	0.9530 0.95274 0.027/0.10	0.9618 0.96133 0.049/0.10	0.9692 0.96821 0.102/0.10	0.9740 0.97382 0.102/0.10	0.9740 0.97382 0.102/0.10	0.9740 0.97382 0.102/0.10	
2	0.7154 0.71433 0.150/0.25	0.7972 0.79670 0.062/0.10	0.8455 0.84585 -0.041/0.10	0.8792 0.87917 0.003/0.10	0.9035 0.90336 0.015/0.10	0.9221 0.92172 0.041/0.10	0.9370 0.93610 0.097/0.10	0.9477 0.94763 0.008/0.10	0.9523 0.9510 0.041/0.10	0.9689 0.9684 0.005/0.10	0.9746 0.9739 0.007/0.10	
3		0.6450 0.64574 -0.115/0.10	0.7508 0.75080 0.000/0.10	0.8108 0.81092 -0.015/0.10	0.8517 0.85155 0.018/0.10	0.8811 0.88115 -0.006/0.10	0.9039 0.90374 0.018/0.10	0.9212 0.92152 -0.035/0.10	0.9370 0.93610 0.097/0.10	0.9477 0.94763 0.008/0.10	0.9523 0.9510 0.041/0.10	
4			0.6308 0.63083 -0.005/0.20	0.7355 0.73508 0.057/0.10	0.7966 0.79698 -0.048/0.10	0.8385 0.83986 -0.141/0.20	0.8718 0.87127 0.061/0.10	0.8962 0.89566 0.061/0.15	0.9127 0.91127 0.052/0.10	0.9272 0.92672 0.052/0.10	0.9427 0.94222 0.052/0.10	
5				0.6492 0.64872 0.075/0.10	0.7390 0.73947 -0.064/0.10	0.7966 0.79751 -0.114/0.20	0.8385 0.83893 -0.052/0.10	0.8697 0.86973 -0.061/0.10	0.8962 0.89617 -0.052/0.10	0.9212 0.92117 -0.052/0.10	0.9427 0.94222 0.052/0.10	
6				0.5506 0.54896 0.299/0.10	0.6786 0.67938 -0.115/0.25	0.7541 0.75510 -0.133/0.25	0.8073 0.80707 0.028/0.10	0.8453 0.84551 -0.025/0.10	0.8811 0.88115 -0.006/0.10	0.9039 0.90374 0.018/0.10	0.9212 0.92152 -0.035/0.10	
7				0.4488 0.44790 0.201/0.10	0.6184 0.61875 -0.037/0.35	0.7123 0.71339 -0.153/0.35	0.7767 0.77623 0.061/0.10	0.8219 0.82183 0.009/0.10	0.8692 0.86917 -0.052/0.10	0.9039 0.90374 0.018/0.10	0.9212 0.92152 -0.035/0.10	
8				0.3931 0.39324 -0.035/0.10	0.5635 0.56323 0.048/0.20	0.6737 0.67401 -0.047/0.30	0.7480 0.74713 0.117/0.10	0.7998 0.79960 0.025/0.10	0.8453 0.84551 -0.025/0.10	0.8811 0.88115 -0.006/0.10	0.9039 0.90374 0.018/0.10	
9				0.3841 0.38407 0.009/0.15	0.5223 0.52155 0.144/0.10	0.6402 0.63933 0.135/0.10	0.7212 0.72069 0.070/0.10	0.7790 0.77927 -0.035/0.10	0.8219 0.82183 0.009/0.10	0.8692 0.86917 -0.052/0.10	0.9039 0.90374 0.018/0.10	
10				0.3932 0.39310 0.024/0.10	0.4990 0.49851 0.099/0.10	0.6132 0.61186 0.220/0.10	0.6980 0.69793 0.009/0.10	0.7609 0.76133 -0.056/0.15	0.8073 0.80707 0.028/0.10	0.8453 0.84551 -0.025/0.10	0.8811 0.88115 -0.006/0.10	
11				0.4091 0.40926 -0.039/0.10	0.4908 0.49132 -0.106/0.10	0.5943 0.59313 0.198/0.10	0.6791 0.67971 -0.090/0.10	0.7457 0.74619 -0.066/0.20	0.7998 0.79960 0.025/0.10	0.8453 0.84551 -0.025/0.10	0.8811 0.88115 -0.006/0.10	
12				0.4284 0.42867 -0.063/0.10	0.4938 0.49468 -0.178/0.10	0.5833 0.58310 0.035/0.10	0.6662 0.66653 -0.050/0.10	0.7344 0.73418 0.030/0.25	0.7790 0.77927 -0.035/0.10	0.8219 0.82183 0.009/0.10	0.8692 0.86917 -0.052/0.10	

[] : the most probable values
 1st line : skeleton table value, Z_{ST}
 2nd line : calculated value, Z_{cal}
 3rd line : deviation(%) / uncertainty(%)
 deviation(%) = $(Z_{ST} - Z_{cal}) / Z_{cal} \times 100$

Table 4-2 (continued)

Pressure MPa	Temperature K (°C)				
	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)
13	0.4496	0.5042	0.5798	0.6584	0.7262
	0.44976	0.50450	0.58052	0.65845	0.72546
	-0.036/0.15	-0.059/0.10	-0.124/0.15	-0.008/0.10	0.103/0.20
14	0.4718	0.5182	0.5830	0.6552	0.7204
	0.47179	0.51825	0.58376	0.65511	0.72001
	0.002/0.20	-0.009/0.15	-0.130/0.15	0.014/0.10	0.054/0.15
15	0.4949	0.5341	0.5912	0.6560	0.7175
	0.49435	0.53447	0.59132	0.65591	0.71768
	0.110/0.25	-0.069/0.10	-0.020/0.15	0.014/0.10	-0.026/0.15
16	0.5177	0.5523	0.6024	0.6604	0.7176
	0.51723	0.55229	0.60202	0.66019	0.71823
	0.090/0.20	0.003/0.15	0.063/0.15	0.031/0.10	-0.087/0.15
17	0.5404	0.5717	0.6158	0.6670	0.7205
	0.54029	0.57116	0.61501	0.66731	0.72133
	0.020/0.20	0.094/0.20	0.129/0.30	-0.047/0.10	-0.115/0.15
18	0.5633	0.5911	0.6304	0.6767	0.7266
	0.56344	0.59076	0.62965	0.67670	0.72667
	-0.024/0.20	0.057/0.20	0.119/0.30	0.000/0.10	-0.009/0.15
19	0.5863	0.6110	0.6455	0.6872	0.7344
	0.58662	0.61086	0.64552	0.68790	0.73392
	-0.054/0.20	0.023/0.20	-0.003/0.20	-0.102/0.10	0.065/0.20
20	0.6094	0.6312	0.6620	0.7000	0.7438
	0.60980	0.63130	0.66230	0.70053	0.74281
	-0.065/0.20	-0.016/0.20	-0.045/0.25	-0.076/0.10	0.133/0.20
25	0.7251	0.7359			
	0.72497	0.73587			
	0.018/0.15	0.004/0.15			
30	0.8382	0.8412			
	0.83829	0.84112			
	-0.011/0.15	0.009/0.10			
35	0.9494	0.9453			
	0.94959	0.94547			
	-0.020/0.15	-0.018/0.10			
40	1.0588	1.0479			
	1.05897	1.04850			
	-0.016/0.15	-0.057/0.15			
45	1.1665	1.1501			
	1.16660	1.15012			
	-0.008/0.20	-0.002/0.20			
50	1.2727	1.2505			
	1.27263	1.25037			
	0.006/0.20	0.011/0.20			
60	1.4806	1.4474			
	1.48043	1.44704			
	0.011/0.20	0.025/0.20			

in Table 1.

Comparison of the compressibility factor values computed from Eq. (1) with the skeleton table values and also with the experimental data of both propane¹⁰⁻¹⁵⁾ and propene¹⁶⁻¹⁸⁾ were conducted. It

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Table 5 Numerical constants in Eq. (3) for propane and propene

	Propane	Propene		Propane	Propene
d_1	$-1.184\ 5823 \times 10^4$	$-1.360\ 6591 \times 10^4$	b_{12}	$5.761\ 1507 \times 10^6$	$7.751\ 9414 \times 10^7$
d_2	$1.257\ 4194 \times 10^2$	$2.671\ 0580 \times 10^2$	b_{13}	$-8.161\ 0172 \times 10^9$	$-5.390\ 6536 \times 10^{10}$
d_3	$-1.273\ 7055 \times 10^{-1}$	$-2.362\ 4147 \times 10^{-2}$	b_{14}	$3.401\ 9827 \times 10^{14}$	$3.834\ 1277 \times 10^{15}$
d_4	$9.596\ 8764 \times 10^{-6}$	$-4.524\ 8282 \times 10^{-5}$	b_{15}	$1.053\ 6524 \times 10^{22}$	$-1.406\ 1663 \times 10^{22}$
d_5	$2.539\ 2061 \times 10^{-9}$	$1.940\ 3623 \times 10^{-8}$	b_{16}	$3.638\ 6947 \times 10^{11}$	$-1.074\ 4115 \times 10^{13}$
d_5	$4.650\ 7610 \times 10^0$	$-2.377\ 7028 \times 10^1$	b_{17}	0	$1.234\ 4220 \times 10^{16}$
b_1	$-4.090\ 9899 \times 10^2$	$1.770\ 6253 \times 10^3$	b_{18}	0	$-4.554\ 3334 \times 10^{18}$
b_2	$6.221\ 3928 \times 10^5$	$-1.407\ 2709 \times 10^6$	b_{19}	$-6.955\ 9033 \times 10^{18}$	$5.352\ 2650 \times 10^{20}$
b_3	$-4.269\ 9835 \times 10^{11}$	$2.815\ 5700 \times 10^{10}$	b_{20}	$-3.696\ 5023 \times 10^{13}$	$5.120\ 4682 \times 10^{14}$
b_4	$6.987\ 0832 \times 10^{16}$	$-1.982\ 3817 \times 10^{15}$	b_{21}	$1.660\ 5316 \times 10^{16}$	$-5.953\ 6320 \times 10^{17}$
b_5	$-6.741\ 6069 \times 10^{21}$	$-8.976\ 3010 \times 10^{19}$	b_{22}	0	$2.277\ 0005 \times 10^{20}$
b_6	$2.827\ 2012 \times 10^{26}$	$5.317\ 8697 \times 10^{24}$	b_{23}	0	$-2.835\ 8570 \times 10^{22}$
b_7	$-2.187\ 7931 \times 10^{35}$	0	b_{24}	$3.341\ 9911 \times 10^5$	0
b_8	$-6.474\ 1658 \times 10^4$	$-3.783\ 7044 \times 10^5$	b_{25}	$-4.064\ 7594 \times 10^8$	0
b_9	$1.593\ 2143 \times 10^8$	$3.554\ 6610 \times 10^8$	b_{26}	$6.923\ 3929 \times 10^{13}$	$4.048\ 8404 \times 10^{12}$
b_{10}	0	$-7.527\ 8673 \times 10^{10}$	b_{27}	$-1.458\ 5349 \times 10^{18}$	0
b_{11}	$-2.295\ 1780 \times 10^{13}$	$-3.711\ 0382 \times 10^{11}$	γ	$1.944\ 4748 \times 10^4$	$2.479\ 0640 \times 10^4$

should be noted that the comparison with the available data was performed only with those taken into consideration for the establishment of the skeleton tables in the previous work by Date and Iwasaki¹⁾. The average deviation of these reported experimental data from Eq. (1) are shown in Table 2 and it can be understood that the computed compressibility factor values are in satisfactory agreement with the skeleton table values and the experimental data which were evaluated to be found more reliable by the HPDCJ¹⁾. The computed compressibility factor values as well as their comparison with the skeleton table values are tabulated for propane and propene in Tables 3 and 4, respectively.

It is confirmed that Eq. (1) can reproduce satisfactorily the skeleton table values of propane and propene for the whole temperature ranges assigned within the gaseous phases. But, simply because of the fact that the derived values with respect to the isobaric specific heat capacity are less reliable along the two bounded isotherms of 298.15 K and 548.15 K for propane, the effective range of the present equation of state for gaseous propane is limited to somewhat narrow region as mentioned previously and therefore those computed values in this limited range of temperature are only given in Table 3. On the other hand, the derived values of the isobaric specific heat capacity for propene are not reasonable only along the isotherm of 373.15 K for supercritical pressures and hence this region is excluded from the effective range of the proposed equation as shown in Table 4, however the P - V - T behavior along this isotherm is completely satisfactory. It may be understood that this kind of behavior is mainly due to the difficulty of fitting the P - V - T plane alone without considering the tendency of the derived property values especially in such a vicinity of the critical isotherm as 373.15 K for gaseous propene.

Table 6-1 Calculated values of molar volume, molar enthalpy and molar entropy for gaseous propane

Pressure MPa	Temperature K (°C)										
	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)	523.15 (250)
0.1	22245	24391	26529	28657	30776	32888	34994	37095	39194	41289	43382
	-1903	-112.8	1805	3855	6033	8332	10750	13290	15940	18700	21570
	-6.115	0.1128	6.285	12.40	18.43	24.40	30.29	36.11	41.86	47.55	53.17
0.5		4533.1	5019.1	5491.2	5951.3	6402.2	6846.5	7286.0	7721.9	8154.9	8585.6
		-608.9	1362	3474	5706	8050	10500	13070	15740	18520	21410
		-14.38	-8.038	-1.745	4.446	10.52	16.50	22.39	28.19	33.92	39.57
1			2308.3	2583.8	2841.9	3088.1	3326.4	3559.2	3787.9	4013.5	4236.7
			723.7	2948	5269	7680	10180	12790	15490	18300	21210
			-15.21	-8.581	-2.143	4.108	10.20	16.18	22.05	27.83	33.53
2				1099.3	1273.0	1424.3	1563.3	1694.7	1821.1	1943.7	2063.5
				1641	4266	6866	9498	12190	14970	17830	20790
				-17.16	-9.874	-3.129	3.282	9.469	15.49	21.39	27.19
3					729.26	861.46	972.24	1072.2	1165.6	1254.6	1340.4
					2976	5923	8745	11560	14430	17360	20370
					-15.92	-8.278	-1.403	5.066	11.28	17.32	23.22
4					415.73	570.69	673.64	760.19	838.20	910.89	979.88
					893.9	4774	7902	10890	13860	16870	19940
					-23.02	-12.93	-5.306	1.545	7.996	14.20	20.21
5						383.73	491.60	572.46	642.11	705.41	764.53
						3256	6944	10160	13260	16360	19500
						-17.93	-8.933	-1.550	5.192	11.58	17.73
6						246.01	368.03	447.20	511.93	569.22	621.86
						1044	5840	9375	12640	15850	19060
						-24.26	-12.55	-4.426	2.673	9.274	15.57
7						173.25	280.27	358.34	419.76	472.81	520.83
						-1028	4597	8542	12000	15330	18620
						-29.98	-16.25	-7.179	0.3410	7.182	13.64
8						148.13	221.17	293.55	351.79	401.48	445.92
						-2053	3368	7681	11350	14800	18180
						-32.95	-19.74	-9.824	-1.851	5.247	11.87
9						136.47	185.81	246.57	300.56	347.11	388.56
						-2612	2388	6845	10700	14270	17740
						-34.71	-22.53	-12.29	-3.914	3.441	10.23
10						129.48	165.19	213.42	261.66	304.87	343.59
						-2970	1694	6101	10070	13750	17300
						-35.94	-24.58	-14.46	-5.829	1.752	8.705
11						124.66	152.28	190.45	232.17	271.69	307.74
						-3221	1201	5485	9496	13260	16880
						-36.89	-26.12	-16.28	-7.570	0.1814	7.279
12						121.03	143.50	174.36	209.88	245.46	278.84
						-3406	837.7	4995	8985	12800	16480
						-37.67	-27.33	-17.78	-9.116	-1.267	5.948
13						118.16	137.09	162.73	192.97	224.65	255.32
						-3548	560.3	4606	8547	12370	16100
						-38.32	-28.32	-19.03	-10.47	-2.588	4.710
14						115.80	132.16	154.00	179.98	208.05	236.07
						-3659	342.5	4294	8176	11990	15740
						-38.90	-29.15	-20.07	-11.64	-3.782	3.564
15						113.80	128.23	147.21	169.81	194.70	220.20
						-3746	168.1	4041	7865	11660	15420
						-39.40	-29.87	-20.97	-12.67	-4.857	2.507
16						112.07	124.99	141.76	161.69	183.86	207.04
						-3815	26.34	3833	7603	11370	15120
						-39.86	-30.50	-21.76	-13.57	-5.823	1.536

1st line : molar volume V in $\text{cm}^3 \cdot \text{mol}^{-1}$ 2nd line : molar enthalpy H in $\text{J} \cdot \text{mol}^{-1}$ 3rd line : molar entropy S in $\text{J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$

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Table 6-2 (continued)

Pressure MPa	Temperature K (°C)					
	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)	523.15 (250)
17	110.55	122.25	137.28	155.06	174.95	196.03
	-3869	-89.94	3660	7382	11110	14860
	-40.28	-31.07	-22.46	-14.38	-6.694	0.6451
18	109.19	119.90	133.51	149.55	167.52	186.76
	-3911	-185.9	3514	7193	10890	14620
	-40.66	-31.58	-23.09	-15.10	-7.481	-0.1729
19	107.98	117.85	130.29	144.89	161.25	178.87
	-3943	-265.2	3391	7032	10700	14410
	-41.01	-32.05	-23.66	-15.75	-8.197	-0.9250
20	106.87	116.03	127.49	140.89	155.88	172.10
	-3966	-330.8	3285	6893	10530	14220
	-41.34	-32.48	-24.13	-16.34	-8.851	-1.618
25	102.51	109.26	117.50	126.99	137.55	148.98
	-3989	-512.8	2956	6433	9957	13560
	-42.71	-34.24	-26.28	-18.73	-11.47	-4.417
30					126.64	
					9654	
					-13.40	
1st line : molar volume V in $\text{cm}^3 \cdot \text{mol}^{-1}$						
2nd line : molar enthalpy H in $\text{J} \cdot \text{mol}^{-1}$						
3rd line : molar entropy S in $\text{J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$						

Basic Correlating Function

When density and temperature are chosen as the independent variables, the expressions for pressure and all other thermodynamic properties can be derived directly by the partial differentiation of a basic correlating function $A=A(\rho, T)$, where A is the molar Helmholtz function. In the present study, the molar Helmholtz function A in $\text{J} \cdot \text{mol}^{-1}$ is derived from Eqs. (1) and (2) as follows:

$$\begin{aligned}
 A = & d_1 + d_2 T + d_3 T^2 + d_4 T^3 + d_5 T^4 + d_6 T \cdot \ln T + RT \cdot \ln \rho \\
 & + (b_1 T + b_2 + b_3/T^2 + b_4/T^4 + b_5/T^6 + b_6/T^8 + b_7/T^{12})\rho \\
 & + (b_8 T + b_9 + b_{10}/T + b_{11}/T^2)\rho^2 + (b_{12} T + b_{13} + b_{14}/T^2 + b_{15}/T^5)\rho^3 \\
 & + (b_{16} + b_{17}/T + b_{18}/T^2 + b_{19}/T^3)\rho^4 \\
 & + (b_{20} + b_{21}/T + b_{22}/T^2 + b_{23}/T^3)\rho^5 \\
 & + (b_{24} T + b_{25} + b_{26}/T^2 + b_{27}/T^4)[1/\gamma - (\rho^2/2 + 1/\gamma) \exp(-\gamma \rho^2)]. \quad (3)
 \end{aligned}$$

The numerical constants in Eq. (3) are given in Table 5. The numerical values of d_1 and d_2 in Eq. (3) are fixed due to the following specified conditions:

- (i) Molar entropy, $S=0 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$ at 298.15 K and 0.101325 MPa,
- (ii) Molar enthalpy, $H=0 \text{ J} \cdot \text{mol}^{-1}$ at 298.15 K and 0 MPa.

Derived Functions

Table 7-1 Calculated values of molar volume, molar enthalpy and molar entropy for gaseous propene

Pressure MPa	Temperature K (°C)										
	248.15 (-25)	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)
0.1	20110 -3179 -11.13	22286 -1691 -5.423	24439 -110.4 0.1129	26574 1558 5.485	28697 3315 10.72	30810 5164 15.85	32917 7105 20.88	35019 9140 25.84	37118 11270 30.72	39215 13490 35.55	41310 15800 40.31
0.5			4586.6 -590.7 -14.40	5067.9 1168 -8.734	5532.1 2989 -3.305	5985.3 4884 1.950	6431.2 6860 7.073	6871.9 8921 12.09	7309.0 11070 17.03	7743.2 13310 21.89	8175.3 15640 26.68
1			2071.9 -1312 -21.93	2362.7 615.6 -15.72	2627.3 2545 -9.969	2877.1 4512 -4.512	3117.6 6540 0.7458	3352.0 8640 5.860	3582.0 10820 10.86	3808.9 13080 15.77	4033.4 15430 20.61
2				959.63 -878.0 -25.02	1153.1 1478 -17.99	1312.1 3673 -11.90	1455.2 5843 -6.273	1589.1 8042 -0.9174	1717.2 10290 4.253	1841.3 12610 9.287	1962.5 15010 14.21
3					623.07 -69.11 -24.90	776.45 2645 -17.37	894.82 5053 -11.12	998.65 7393 -5.417	1094.4 9740 -0.0279	1185.1 12130 5.156	1272.3 14570 10.19
4						489.29 1258 -22.75	608.35 4129 -15.29	700.99 6880 -9.078	782.19 9152 -3.400	856.89 11620 1.968	927.41 14130 7.130
5							429.50 3004 -19.41	520.33 5888 -12.38	594.32 8528 -6.314	660.07 11100 -0.7214	720.87 13680 4.588
6							302.88 1562 -23.94	398.37 5003 -15.54	468.93 7864 -8.973	529.17 10560 -3.109	583.66 13220 2.369
7							211.82 -227.4 -29.07	310.99 4021 -18.70	379.74 7163 -11.48	436.24 10010 -5.297	486.27 12760 0.3698
8							162.72 -1725 -33.30	247.70 2980 -21.81	313.93 6436 -13.87	367.40 9444 -7.337	413.97 12290 -1.466
9							141.27 -2587 -35.84	203.88 1989 -24.69	264.69 5706 -16.14	315.02 8878 -9.253	358.62 11830 -3.172
10							130.13 -3101 -37.47	175.39 1166 -27.08	227.98 5008 -18.25	274.56 8322 -11.05	315.33 11370 -4.765
11							123.16 -3444 -38.65	157.14 537.7 -28.95	200.91 4377 -20.13	243.09 7791 -12.72	280.96 10930 -6.253
12							118.26 -3693 -39.58	145.03 68.30 -30.42	181.06 3833 -21.77	218.51 7298 -14.25	253.40 10500 -7.639
13							114.53 -3882 -40.34	136.53 -287.2 -31.59	166.39 3379 -23.17	199.26 6852 -15.63	231.13 10110 -8.924
14							111.56 -4031 -41.00	130.24 -562.9 -32.56	155.37 3004 -24.37	184.08 6457 -16.87	213.01 9738 -10.11
15							109.10 -4151 -41.58	125.36 -781.8 -33.38	146.89 2696 -25.39	172.02 6113 -17.97	198.17 9402 -11.20
16							107.20 -4249 -42.10	121.44 -958.9 -34.09	140.20 2441 -26.28	162.32 5815 -18.95	185.92 9098 -12.19

1st line : molar volume V in $\text{cm}^3 \cdot \text{mol}^{-1}$ 2nd line : molar enthalpy H in $\text{J} \cdot \text{mol}^{-1}$ 3rd line : molar entropy S in $\text{J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$

Thermodynamic Properties of Gaseous Propane and Propene

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Table 7-2 (continued)

Pressure MPa	Temperature K (°C)				
	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)
17	105.21	118.21	134.80	154.42	175.74
	-4331	-1104	2230	5558	8827
	-42.57	-34.71	-27.06	-19.83	-13.10
18	103.62	115.47	130.34	147.90	167.21
	-4399	-1226	2053	5337	8585
	-43.00	-35.28	-27.75	-20.62	-13.93
19	102.21	113.11	126.59	142.43	159.99
	-4455	-1327	1904	5147	8371
	-43.40	-35.79	-28.37	-21.32	-14.69
20	100.93	111.05	123.39	137.79	153.83
	-4502	-1413	1777	4984	8181
	-43.78	-36.25	-28.93	-21.97	-15.38
25	95.997	103.56			
	-4639	-1683			
	-45.35	-38.16			
30	92.502	98.643			
	-4670	-1795			
	-46.62	-39.61			
35	89.814	95.040			
	-4638	-1819			
	-47.68	-40.81			
40	87.640	92.222			
	-4564	-1786			
	-48.61	-41.84			
45	85.820	89.920			
	-4459	-1715			
	-49.43	-42.75			
50	84.258	87.982			
	-4331	-1616			
	-50.18	-43.57			
60	81.680	84.851			
	-4026	-1359			
	-51.49	-45.00			

1st line : molar volume

V in cm³·mol⁻¹

2nd line : molar enthalpy

H in J·mol⁻¹

3rd line : molar entropy

S in J·K⁻¹·mol⁻¹

According to the general thermodynamic relations, the pressure P in MPa, the molar entropy S in J·K⁻¹·mol⁻¹, the molar enthalpy H in J·mol⁻¹, the molar isobaric specific heat capacity C_p in J·K⁻¹·mol⁻¹ and the molar isochoric specific heat capacity C_v in J·K⁻¹·mol⁻¹ can be calculated by the following expressions:

$$P = \rho^2 (\partial A / \partial \rho)_T, \quad (4)$$

$$S = -(\partial A / \partial T)_\rho, \quad (5)$$

$$H = A - T(\partial A / \partial T)_\rho + \rho(\partial A / \partial \rho)_T, \quad (6)$$

$$C_p = T \left[-(\partial^2 A / \partial T^2)_\rho + \frac{\rho(\partial^2 A / \partial \rho \partial T)^2}{2(\partial A / \partial \rho)_T + \rho(\partial^2 A / \partial \rho^2)_T} \right], \quad (7)$$

$$C_v = -T(\partial^2 A / \partial T^2)_\rho. \quad (8)$$

In addition, the compressibility factor Z and the molar volume V in cm³·mol⁻¹ can be calculated from the following expressions, respectively:

$$Z = P / RT\rho, \quad (9)$$

$$V = 1 / \rho. \quad (10)$$

Calculated Thermodynamic Properties

By differentiating the new equations of state expressed in the basic correlating functions for gaseous propane and propene, Eq. (3), all of the thermodynamic properties may be calculated as shown in the previous section. The calculated molar volume, the molar enthalpy and the molar entropy for both gaseous propane and propene are tabulated in Tables 6 and 7, respectively.

With respect to the molar isobaric specific heat capacity for both propane and propene, the calculated results are shown on C_p - ρ diagrams in Figs. 3 and 4. It is also noteworthy that the calculated C_p values for gaseous propene are in good agreement with the reported experimental data by Bier *et al.*⁸⁾, where they overlap. The average deviation is found as 0.362% with respect to 96 data points compared.

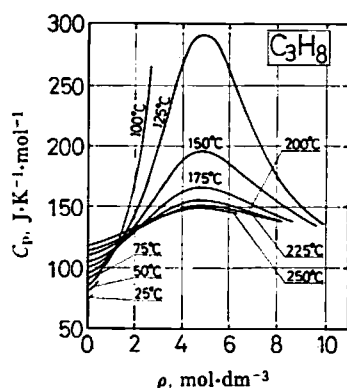


Fig. 3 Calculated molar isobaric specific heat capacity for propane

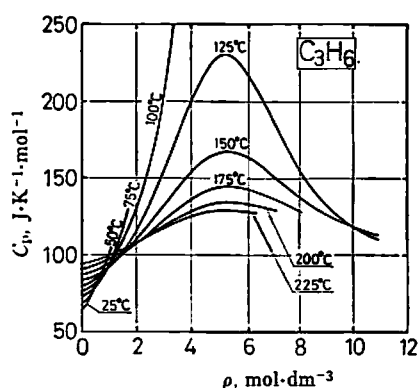


Fig. 4 Calculated molar isobaric specific heat capacity for propene

Conclusion

As a part of the activities of the High Pressure Data Center of Japan, new equations of state, Eq. (1), for both gaseous propane and propene are formulated based upon the most probable and additional recommended compressibility factor values proposed previously by the HPDCJ. The present formulations given as a function of the density and temperature can cover the range of temperature 273.15 K–523.15 K and pressures up to 30 MPa for propane, and also that of temperature 248.15 K–498.15 K and pressures up to 60 MPa for propene, respectively.

Based upon the established equations of state, the basic correlating functions given as the molar Helmholtz function are derived and hence the additional thermodynamic property values such as molar volume, molar entropy, molar enthalpy and molar isobaric specific heat capacity, are also calculated and presented.

It was also confirmed that the so-called extended BWR equations are very effective to cover the wide range of the state parameters in gaseous region especially for the serial hydrocarbons like ethane, ethene, propane and propene in the previous and present studies by the present authors.

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