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## EVALUATION AND CORRELATION OF VISCOSITY DATA

The Most Probable Values of the Viscosity of Gaseous  
Propane and Propylene

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The critical evaluation of the viscosity data of gaseous propane and propylene has been carried out based on the experimental data available in literature. The most probable values of the viscosity of propane are presented in the form of numerical tables covering the range of temperatures from 298.15 to 523.15 K and that of pressures up to  $550 \times 10^5$  Pa. The estimated uncertainties of the tabulated values are also given. Since there exist only three sets of experimental data available in literature for propylene, the smoothed values are generated on the basis of these data covering the range of temperatures from 300 to 525 K and that of pressures up to  $800 \times 10^5$  Pa.

## Introduction

In the previous papers the results of the evaluation and correlation of the viscosity data of gaseous methane<sup>1)</sup>, ethane and ethylene<sup>2)</sup> under high pressure were already reported. The present work on propane and propylene is another successive program of "High Pressure Data Center of Japan" organized in the Society of Materials Science, Japan, with the sponsorship of the Agency of Science and Technology. The following members attended several meetings for the discussion and the final evaluation:

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

## Survey and Evaluation of Viscosity Data

There exist nine and three original measurements of the viscosity of gaseous propane and propylene under high pressure, respectively. In Table 1, the authors, the temperature and pressure ranges, and numbers of isotherms are listed in the order of the publication. The original papers were carefully read through and examined from the viewpoint of the reliability of the reported data in the similar manner to the previous works<sup>1,2)</sup>. The final evaluation was performed by the Committee members described above.

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1) T. Makita, Y. Tanaka and A. Nagashima, *This Journal* **43**, 54 (1973)

2) T. Makita, Y. Tanaka and A. Nagashima, *ibid.*, **44**, 98 (1974)

Table 1 Measurements of the viscosity of gaseous propane and propylene under high pressure

First Author	Year	Method	Temp. Range (K)	Press. Range (10 <sup>5</sup> Pa)	No. of isotherms	Ref.
<b>Propane</b>						
Sage	1938	Rolling Ball	311-378	1- 138	5	3)
Smith	1943	Rolling Ball	295-463	7- 345	8	4)
Bicher	1943	Rolling Ball	298-498	1- 345	5	5)
Comings	1944	Transpiration	303-378	1- 42.3	6	6)
Golubev	1953	Transpiration	298-523	1- 810	8	7)
Baron	1959	Transpiration	325-408	7- 552	4	8)
Starling	1960	Transpiration	294-511	1- 552	11	9)
			311-422	621-1379	8	
Carmichael	1964	Rotating Cylinder	278-478	1- 345	7	10)
Giddings	1966	Transpiration	278-378	1- 551	4	11)
<b>Propylene</b>						
Golubev	1953	Transpiration	291-523	1- 810	7	7)
Neduzhii	1967	Transpiration	210-310	1- 7.8	6	12)
Naziev	1972	Transpiration	300-474	1- 9.2	6	13)

As the results for propane, three sets of data presented by Starling *et al.*<sup>9)</sup>, Carmichael *et al.*<sup>10)</sup> and Giddings *et al.*<sup>11)</sup> were evaluated to be the most reliable and given the highest weight. The weight second to the above was given to three sets of data reported by Comings *et al.*<sup>6)</sup>, Golubev *et al.*<sup>7)</sup>, and Baron *et al.*<sup>8)</sup> No weight was given to the earlier works<sup>3-5)</sup> using the rolling-ball method.

For propylene, there exist only three sets of experimental data which include the viscosity values in the gas phase under high pressure. Among them, Neduzhii *et al.*<sup>12)</sup> and Naziev *et al.*<sup>13)</sup> failed to cover the wide range of pressures, while Golubev *et al.*<sup>7)</sup> covered the pressure range up to  $810 \times 10^5$  Pa (=bar). Therefore only the smoothed values were generated on the basis of these data weighted equally.

### Method and Results of Correlation

#### Propane

(i) *Viscosity at the atmospheric pressure* : For the viscosity of gaseous propane at the atmospheric pressure there exist fifteen sets of experimental data available in literature. Therefore a correlation between viscosity and temperature was carried out on the basis of several sets of these data quite independently of the high pressure data. The viscosity at the atmospheric pressure was

3) B. H. Sage and W. N. Lacey, *Ind. Eng. Chem.*, **30**, 829 (1938)

4) A. S. Smith and G. G. Brown, *ibid.*, **35**, 705 (1943)

5) L. B. Bicher, Jr. and D. L. Katz, *ibid.*, **35**, 754 (1943)

6) E. W. Comings, B. J. Mayland and R. S. Egly, Univ. of Illinois. Engs. Exp. Sta., Bull. Series No. 354 (1944)

7) I. F. Golubev and V. A. Petrov, *Trudy GIAP*, No. 2, 5 (1953)

8) J. D. Baron, J. G. Roof and F. W. Wells, *J. Chem. Eng. Data*, **4**, 283 (1959)

fitted to the following quartic equation as a function of temperature :

$$\begin{aligned} \eta_0 = & -6.324414 \times 10^2 + 9.039817T - 2.294407 \times 10^{-2}T^2 \\ & + 3.681679 \times 10^{-5}T^3 - 2.303256 \times 10^{-8}T^4 \end{aligned} \quad (1)$$

where  $\eta_0$  is the viscosity at the normal pressure in  $10^{-8}$  Pa·s ( $=10^{-7}$  poise) and  $T$  the temperature in K. Eq. (1) is found to fit the experimental data for propane between 278 and 549K with the standard deviation of 0.78% and the maximum of 2.0%. The deviations of the original data from the above equation are plotted in Fig. 1.

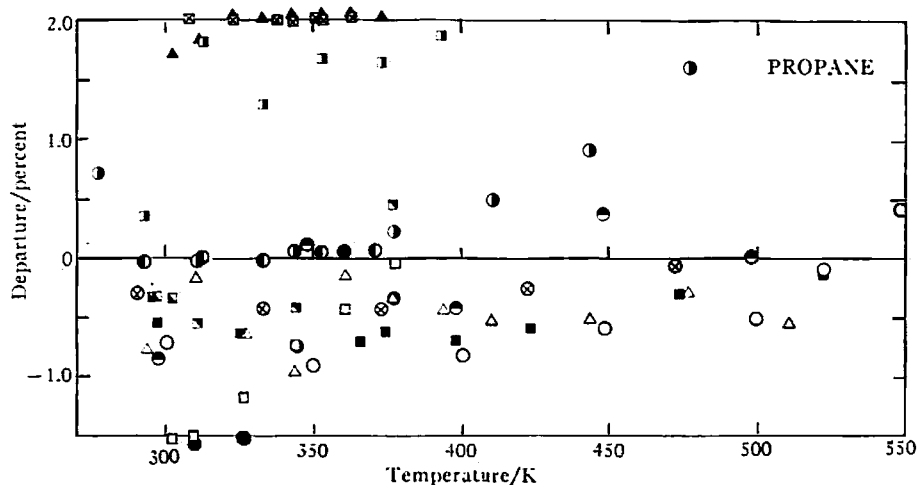


Fig. 1 Departure plots of original viscosity data for propane at the normal pressure in literature

●: (3), ▲: (5), □: (6), ■: (7), △: (9), ⊙: (10), ■: (11),  
 ▤: (15), ○: (16), ⊗: (17), ▲: (18), ●: (19), ⊠: (20), ▤: (21).

(ii) *Viscosity at high pressures*: The method of the correlation is quite same as used in our previous papers<sup>1,2,14</sup>. The weighted mean value of the viscosity at each grid-point was calculated with the relative weight determined in the critical evaluation. The standard deviations were also calculated by the following equation:

$$\sigma_1 = \sqrt{\frac{\sum \omega_i (\eta_i - \bar{\eta})^2}{\sum \omega_i \cdot (n-1)}} \quad (2)$$

where,  $\omega_i$  = the weight given.

- 9) K. E. Starling, B. E. Eakin and R. T. Ellington, *A. I. Ch. E. Journal*, **6**, 438 (1960)
- 10) L. T. Carmichael, V. M. Berry and B. H. Sage, *J. Chem. Eng. Data*, **9**, 411 (1964)
- 11) J. G. Giddings, J. T. F. Kao and R. Kobayashi, *J. Chem. Phys.*, **45**, 578 (1966)
- 12) I. A. Neduzhii and Yu. I. Khmara, Kiev Technological Institute of Light Industry Publishing House, p. 18 (1967)
- 13) Ya. M. Naziev, S. O. Gusejnov and A. K. Akhmedov, *Izv. Vyssh. Ucheb. Zaved., Neft Gaz.*, **15** (6), 65 (1972)
- 14) Y. Takezaki, "Proceedings of the First Technical Meeting on the Evaluation of Physical Properties of Fluids under Pressures" (Edited by T. Makita), p. 8 (1975)
- 15) T. Titani, *Bull. Chem. Soc. Japan*, **5**, 98 (1930)

$\eta_1$  = the viscosity in the original work,

$\bar{\eta}$  = the weighted mean value,

$n$  = the number of data.

The weighted mean values at  $1.01 \times 10^5$  Pa determined by the grid-point method were found to deviate a little from Eq. (1). Therefore the weighted mean values at low pressures (1, 5 and  $10 \times 10^5$  Pa) were slightly adjusted using the correlated values generated by Eq. (1) so that the weighted mean values at high pressure should be consistent with the correlated values throughout the range of temperature of this correlation. The final weighted mean values are tabulated in Table 2 together with

Table 2 Weighted mean values of the viscosity of propane in  $10^{-8}$  Pa-s ( $10^{-7}$  Poise)

T(K) (°C)	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	498.15	523.15
P (bar)	25	50	75	100	125	150	175	200	225	250
1	817	884	949	1012	1075	1136	1195	1254	1310	1360*
5	821	892	962	1024	1087	1147	1205	1265	1318	1370*
10		902	980	1040	1104	1162	1218	1280	1328	1380*
20	9983( 67)	7478	1025( 4)	1083( 4)	1145( 8)	1197( 9)	1250(10)	1311(10)	1351(15)	1390*
30	10140( 40)	7662(30)	5408(86)	1179( 4)	1214(11)	1251(12)	1293(11)	1345(11)	1379(13)	1410*
40	10310( 60)	7885(23)	5757(54)	1376( 5)	1325( 7)	1321( 9)	1348( 9)	1395( 9)	1422( 4)	1440*
50	10450( 50)	8136(52)	6079(40)	3393(58)	1536(26)	1434( 2)	1418( 6)	1459( 9)	1488( 1)	1480*
60	10640( 50)	8338(38)	6334(39)	4236(13)	2077(80)	1572(37)	1558( 6)	1580(28)	1517( 5)	1540*
70	10830( 50)	8529(38)	6579(54)	4727(21)	2784(38)	1867(30)	1692(24)	1675(18)	1615(73)	1600*
80	11010( 50)	8720(42)	6805(43)	5075(28)	3526(69)	2255(32)	1881(20)	1779( 9)	1736(63)	1690*
90	11200( 50)	8886(43)	7024(41)	5356(29)	3803(32)	2680(18)	2130( 3)	1921(20)	1803(92)	1790*
100	11350( 90)	9064(44)	7227(36)	5591( 4)	4121(15)	3022( 8)	2368( 5)	2095(19)	2014(93)	1900*
120	11690( 50)	9396(43)	7579(34)	6024(29)	4681(13)	3607( 3)	2860(24)	2455(24)	2325(19)	2120*
140	12020( 60)	9714(42)	7909(32)	6402(30)	5134(17)	4092(13)	3313(36)	2828(28)	2614(10)	2350*
160	12320( 60)	10020(40)	8226(32)	6750(29)	5519(16)	4506(20)	3721(44)	3187(32)	2886(13)	2580*
180	12620( 60)	10320(40)	8533(34)	7077(29)	5862(14)	4869(23)	4087(48)	3520(34)	3145( 5)	2800*
200	12910( 60)	10620(40)	8831(39)	7385(31)	6172(16)	5194(23)	4418(49)	3826(34)	3392( 7)	3020*
250	13630( 70)	11320(50)	9526(46)	8072(38)	6854(20)	5893(20)	5141(39)	4502(30)	3969(23)	3530*
300	14330( 80)	11980(60)	10170(50)	8704(42)	7476(22)	6512(11)	5763(24)	5098(18)	4499(20)	4030*
350	14990(120)	12600(80)	10780(60)	9308(55)	8061(34)	7089( 6)	6322(25)	5641(16)	4992(16)	4510*
400	15630(120)	13210(80)	11380(60)	9876(50)	8589(38)	7621(14)	6854(15)	6152( 4)	5457(22)	4980*
450	16180(200)	13830(80)	11950(60)	10410(40)	9083(48)	8125(33)	7363(16)	6641( 2)	5907(32)	5430*
500	16800(200)	14410(80)	12500(70)	10910(50)	9566(68)	8610(50)	7842(22)	7099( 6)	6338(35)	5840*
550	17410(200)	14940(60)	13020(50)	11420(40)	10040(70)	9065(68)	8304(14)	7545(13)	6706(52)	6210*
600	17600*	15300*	13300*	11800*	10600*	9620*	8740*	7910*	7130*	6550*
650	18200*	15900*	13900*	12300*	11100*	10000*	9140*	8280*	7470*	6870
700	18900*	16500*	14400*	12800*	11500*	10500*	9560*	8680*	7840*	7200*
750	19500*	17000*	14900*	13200*	11900*	10900*	10000*	9120*	8260*	7550*
800	20100*	17600*	15400*	13700*	12400*	11300*	10400*	9500*	8630*	7880*

The values with an asterisk were determined by only one experimental data available.

The values enclosed by dotted lines are of liquid phase.

the values of standard deviations given in the parentheses except the adjusted values near the normal pressure. In this procedure, every tabulated value was determined independently of the adjacent values. However the smoothness and the consistency among the values are very good except the values with an asterisk, which were determined from only one experimental data available.

### Propylene

(i) *Viscosity at the atmospheric pressure:* For the viscosity of gaseous propylene at the atmospheric pressure there exist ten sets of experimental data available in literature. The correlation of viscosity and temperature was performed on the basis of several sets of these data. The viscosity data were fitted to the following quartic equation of temperature:

$$\eta_0 = -2.488096 \times 10^2 + 4.974698T - 6.183878 \times 10^{-3}T^2 + 8.022894 \times 10^{-6}T^3 - 4.572703 \times 10^{-9}T^4 \quad (3)$$

Eq. (3) reproduces the original data between 280 and 523K with the standard deviation of 0.42% and the maximum of 1.4%. The deviations of the original data from the above equation are plotted in Fig. 2.

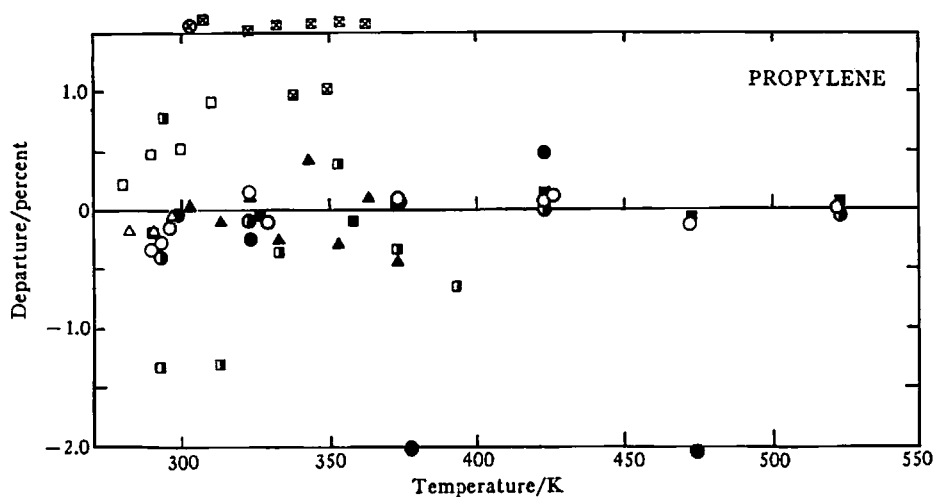


Fig. 2 Departure plots of original viscosity data for propylene at the normal pressure in literature

■: (7), □: (12), ●: (13), ◻: (15), ▲: (18), ⊠: (20), ○: (22),  
△: (23), ◆: (24), ⊗: (25).

- 16) M. Trautz and F. Kurz, *Ann. Physik*, **9**, 981 (1931)
- 17) M. Trautz and K. G. Sorg, *ibid.*, **10**, 81 (1931)
- 18) H. Adzumi, *Bull. Chem. Soc. Japan*, **12**, 199 (1937)
- 19) R. Wobser and Fr. Muller, *Kolloid-Beihfte*, **52**, 165 (1941)
- 20) J. D. Lambert, K. J. Cotton, M. W. Pailthorpe, A. M. Robinson, J. Scrivins, W. R. F. Vale and R. M. Young, *Proc. Roy. Soc. (London)*, **231A**, 280 (1955)
- 21) J. Kestin, S. T. Ro and W. A. Wakeham, *Trans. Faraday. Soc.*, **67**, 2308 (1971)
- 22) M. Trautz and I. Husseini, *Ann. Physik*, **20**, 121 (1934)

(ii) *Viscosity at high pressures*: There exist only three sets of experimental data as shown in Table 1. The data of Neduzhii *et al.* and Naziev *et al.* cover only the lower pressure range below  $10 \times 10^6$  Pa. Thus the sources of data are very scarce and it is impossible to adopt the usual grid-point method for propylene. Therefore only the smoothed values were generated by empirical equations on the basis of available data. It was also found impossible to fit the whole data to a single empirical equation since the viscosity of propylene increases sharply with temperature and pressure near the critical point\*. The original data were divided into two groups in terms of the values of temperature and pressure.

Table 3 Smoothed viscosity values of propylene in  $10^{-7}$  Pa·s ( $10^{-6}$  poise)

T (K) P (bar)	300	325	350	375	400	425	450	475	500	525
1	86.6	94.1	101	108	115	121	128	134	141	147
10	91.0	98.0	105	111	118	123	130	137	144	149
20				116	121	126	133	141	147	152
30				128	126	131	137	145	151	155
40	1010			143	139	139	142	149	155	160
50	1020	788	585	189	157	149	150	155	162	165
60	1040	806	606			168	161	164	168	171
70	1060	823	627			192	175	177	177	177
80	1070	840	647	493		220	189	187	185	184
90	1090	857	667	516		255	213	202	197	190
100	1110	873	686	538	423	312	247	225	211	202
120	1140	904	722	579	468	378	307	267	236	225
140	1170	935	756	618	510	424	350	303	267	253
160	1200	964	788	654	548	463	393	336	297	280
180	1230	993	819	687	584	499	427	368	325	306
200	1260	1020	848	718	617	532	460	398	352	331
250	1330	1090	915	787	688	605	531	465	415	389
300	1400	1150	976	848	749	666	592	525	472	442
350	1460	1210	1030	903	802	719	645	577	524	490
400	1520	1270	1090	954	851	766	692	626	572	535
450	1590	1330	1140	1000	897	811	737	672	618	578
500	1650	1380	1190	1050	942	855	779	713	660	617
550	1710	1440	1240	1100	987	896	820	755	703	658
600	1770	1490	1290	1150	1030	937	864	795	740	693
650	1820	1550	1340	1190	1080	982	907	838	781	733
700	1880	1600	1390	1240	1120	1030	945	871	816	764
750	1940	1650	1440	1280	1160	1060	981	908	849	797
800	1990	1700	1480	1320	1200	1100	1020	938	882	832

The values enclosed by dotted lines are of liquid phase.

\* The critical constants of propylene are as follows:

$$T_c = 365.0 \text{ K}, P_c = 46.2 \times 10^5 \text{ Pa}.$$

In the lower pressure region below about  $90 \times 10^5$  Pa, the smoothed viscosity values were generated employing the following Eq. (4) on the basis of 56 equally weighted data extracted from the three references and correlated values at the normal pressure.

$$\eta = \sum_{j=0}^4 \left( \sum_{i=0}^3 B_{ji} / T^i \right) P^j \quad (4)$$

Eq. (4) fits the original data with the standard deviation of 0.54% and the maximum of 2.2%. The smoothed values obtained were partly adjusted with the aid of the residual viscosity versus density correlation as described later.

Above about  $100 \times 10^5$  Pa, 76 data extracted from Golubev *et al.* were smoothed out by the following form of equation.

$$\eta = \sum_{j=0}^4 \left( \sum_{i=0}^4 B_{ji} T^i \right) P^j \quad (5)$$

The empirical coefficients of the above equation were determined by the least squares method. Eq. (5) reproduces the original viscosity values with the standard deviation of 0.69% and the maximum of 2.6%. The final smoothed viscosity values for propylene are tabulated in Table 3. The tabulated values are found to agree with the correlated values of Vashchenko *et al.*<sup>26)</sup> with the mean deviation of 1.5% and the maximum of 5.3% at 300, 350, 400 and 450K.

### Recommended Viscosity Values of Propane

The weighted mean values given in Table 2, except the supplementary values with an asterisk, were divided into two groups by appropriate values of temperature and pressure taking the sharp increase of viscosity near the critical point\* into consideration, namely the moderate pressure region and the high pressure region. In these two regions the boundary pressure increases from  $20 \times 10^5$  Pa at 298.15K to  $120 \times 10^5$  Pa at 498.15K gradually with temperature. Several source data near the boundary were selected duplicately both in the moderate and the high pressure regions in order to keep smoothness of the data beyond the boundary. Each region has 69 and 143 weighted mean values respectively.

The weighted mean values were correlated employing the following form of equation,

$$\begin{aligned} \eta = & \sum_{i=0}^4 B_{0i} / T^i + \left( \sum_{i=0}^4 B_{1i} / T^i \right) P + \left( \sum_{i=0}^4 B_{2i} / T^i \right) P^2 \\ & + \left( \sum_{i=0}^4 B_{3i} / T^i \right) P^3 + \left( \sum_{i=0}^4 B_{4i} / T^i \right) P^4 \end{aligned} \quad (6)$$

\* The critical constants of propane are as follows:  $T_c = 369.82$ K,  $P_c = 42.50 \times 10^5$  Pa.

23) A. B. van Cleave and O. Maass, *Can. J. Research*, **13B**, 140 (1935)

24) P. M. Craven and J. D. Lambert, *Proc. Roy. Soc.*, (London), **A205**, 439 (1951)

25) H. Senftleben, *Z. angew. Physik*, **5**, 33 (1953)

26) D. M. Vashchenko, *et al.*, "Thermodynamic and Transport Properties of Ethylene and Propylene" (Translated from the Russian as published by the State Committee of Standards of the Soviet Ministry, U. S. S. R.), National Bureau of Standards, U. S. Department of Commerce, Washington, D. C. (1972)

Table 4 Coefficients of Eq. (6) for propane

Coefficient	Moderate pressure region	High pressure region
$B_{00}$	$-4.555477 \times 10^3$	$6.906818 \times 10^5$
$B_{01}$	$1.061704 \times 10^7$	$-9.723551 \times 10^8$
$B_{02}$	$-6.669444 \times 10^9$	$5.016717 \times 10^{11}$
$B_{03}$	$1.746888 \times 10^{12}$	$-1.129728 \times 10^{14}$
$B_{04}$	$-1.669861 \times 10^{14}$	$9.476435 \times 10^{16}$
$B_{10}$	$2.291204 \times 10^3$	$-5.605149 \times 10^3$
$B_{11}$	$-3.584794 \times 10^6$	$7.660571 \times 10^6$
$B_{12}$	$2.088323 \times 10^9$	$-3.825664 \times 10^9$
$B_{13}$	$-5.362933 \times 10^{11}$	$8.361822 \times 10^{11}$
$B_{14}$	$5.123234 \times 10^{13}$	$-6.782749 \times 10^{13}$
$B_{20}$	$-1.544116 \times 10^2$	$1.667698 \times 10$
$B_{21}$	$2.482730 \times 10^5$	$-2.198261 \times 10^4$
$B_{22}$	$-1.489082 \times 10^8$	$1.054318 \times 10^7$
$B_{23}$	$3.946486 \times 10^{10}$	$-2.205222 \times 10^9$
$B_{24}$	$-3.895836 \times 10^{12}$	$1.710478 \times 10^{11}$
$B_{30}$	$1.385320$	$-2.222342 \times 10^{-2}$
$B_{31}$	$-2.135811 \times 10^3$	$2.822039 \times 10$
$B_{32}$	$1.207138 \times 10^6$	$-1.294677 \times 10^4$
$B_{33}$	$-2.927795 \times 10^8$	$2.582008 \times 10^6$
$B_{34}$	$2.513950 \times 10^{10}$	$-1.913313 \times 10^8$
$B_{40}$	$5.500374 \times 10^{-3}$	$1.010817 \times 10^{-5}$
$B_{41}$	$-1.322453 \times 10$	$-1.202900 \times 10^{-2}$
$B_{42}$	$1.138368 \times 10^4$	$5.057963$
$B_{43}$	$-4.231683 \times 10^6$	$-9.065694 \times 10^2$
$B_{44}$	$5.786895 \times 10^8$	$5.970682 \times 10^4$

where  $\eta$  is the viscosity given in  $10^{-8}$  Pa-s,  $T$  the temperature in K and  $P$  the pressure in  $10^5$  Pa. The coefficients are given in Table 4. It is found that the equations are able to reproduce the weighted mean values within the standard deviation of 0.55% and the maximum of 2.1% for the moderate pressure region, and the standard deviation of 0.47% and the maximum of 1.6% for the high pressure region, respectively. The percentage standard deviation  $\sigma_2$  is defined as follows:

$$\sigma_2 = 100 \sqrt{\frac{1}{n} \sum [(\bar{\eta} - \eta_{\text{calc}})/\eta_{\text{calc}}]^2} \quad (7)$$

where  $\bar{\eta}$  = weighted mean values at grid-points.

$\eta_{\text{calc}}$  = calculated values of the viscosity by Eq. (6).

$n$  = number of data points.

The values of percentage standard deviations of original data from Eq. (6) are summarized in Table 5. For some of original data the percentage departures were calculated by the following equation and illustrated in Figs. 3 through 6 as a function of pressure,

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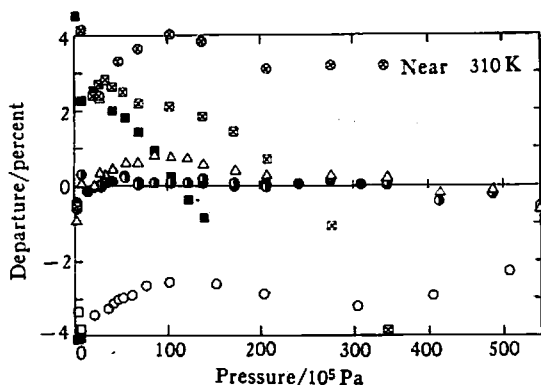


Fig. 3 Percentage departures of the original viscosity data from Eq. (6) for propane under high pressures near 310 K

■: 310.93 K, (3), ☒: 313.45 K, (4), ⊗: 298.15 K, (5),  
□: 310.85 K, (6), ○: 297.65 K, (7), ●: 310.93 K, (9),  
●: 310.93 K, (10), △: 310.93 K, (11).

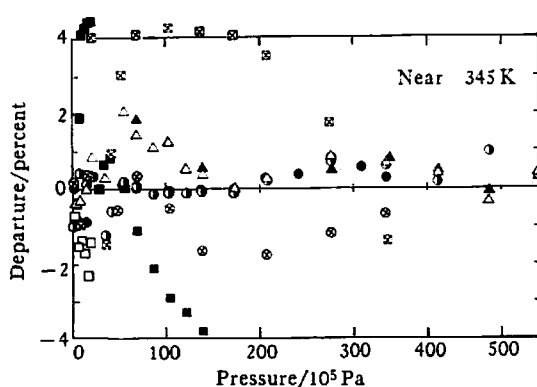


Fig. 4 Percentage departures of the original viscosity data from Eq. (6) for propane under high pressures near 345 K

■: 344.26 K, (3), ☒: 350.35 K, (4), ⊗: 348.15 K, (5),  
□: 344.25 K, (6), ▲: 352.59 K, (8), ●: 344.26 K, (9),  
●: 344.26 K, (10), △: 344.26 K, (11).

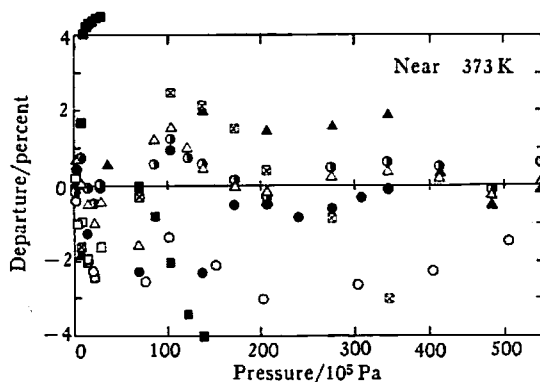


Fig. 5 Percentage departures of the original viscosity data from Eq. (6) for propane under high pressures near 373 K

■: 377.59 K, (3), ☒: 368.15 K, (4), □: 377.65 K, (6),  
○: 373.95 K, (7), ▲: 380.37 K, (8), ●: 377.55 K, (9),  
●: 377.59 K, (10), △: 377.59 K, (11).

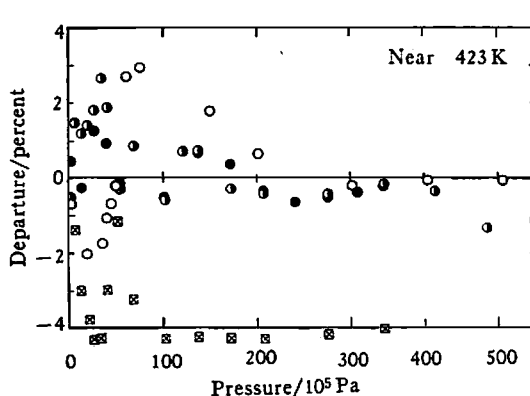


Fig. 6 Percentage departures of the original viscosity data from Eq. (6) for propane under high pressures near 423 K

☒: 423.15 K, (4), ○: 424.15 K, (7), ●: 410.95 K, (9),  
●: 410.93 K, (10).

$$\text{percentage departure} = \frac{\eta_{lit} - \eta_{calc}}{\eta_{calc}} \times 100$$

(8)

where  $\eta_{lit}$  is the original viscosity data. The final recommended viscosity values for propane have been generated by the above Eq. (6) and given in Table 6, covering the temperatures from 300 to 500 K and pressures between 1 and  $550 \times 10^5$  Pa. Eq. (6) is not adequate to reproduce the viscosity values precisely near the critical point as shown by the blanks of the recommended values table.

Table 5 Percentage standard deviations of the original data from Eq. (6) for propane

Author	Moderate pressure region		High pressure region	
	Number of data points compared	Standard deviation %	Number of data points compared	Standard deviation %
Giddings	11	0.59	43	0.72
Carmichael	24	0.86	57	0.69
Starling	56	0.91	129	0.57
Baron	7	1.48	31	2.94
Golubev	28	1.70	58	2.50
Comings	25	2.03		
Smith	34	3.33	57	5.92
Bicher	14	5.72	29	3.83
Sage	34	12.7	37	1.83

Table 6 Recommended values of the viscosity of propane in  $10^{-7}$  Pa-s ( $10^{-6}$  poise)

P (bar) \ T (K)	300	325	350	375	400	425	450	475	500
1	82.1	89.2	95.3	101	108	114	120	126	131
10		90.2	98.3	105	111	117	122	128	134
20	975	729	103	110	115	120	125	131	136
30	993	752	534	119	121	125	130	135	138
40	1010	774	563		132	132	136	140	142
50	1030	796	590		152	143	144	145	146
60	1050	816	616			160	155	154	153
70	1060	836	640	463		185	169	167	162
80	1080	855	664	492	347	221	186	179	173
90	1100	874	686	518	377		208	194	187
100	1110	892	707	543	405	299	234	210	201
120	1150	926	746	589	457	353	281	245	234
140	1180	959	781	630	502	400	326	279	262
160	1210	990	814	667	543	443	367	316	288
180	1240	1020	845	700	579	480	404	348	312
200	1270	1050	873	730	611	514	437	378	336
250	1350	1120	939	797	682	587	509	445	394
300	1420	1180	1000	858	743	648	570	504	447
350	1480	1250	1060	917	800	704	625	557	498
400	1540	1310	1120	974	855	758	678	608	545
450	1600	1380	1180	1030	910	812	729	656	590
500	1660	1430	1240	1080	961	862	778	703	632
550	1720	1490	1280	1130	1000	906	822	745	671

The values enclosed by dotted lines are of liquid phase.

## Residual Viscosity Correlation

The residual viscosity  $\bar{\eta} - \eta_0$  was correlated with density  $\rho$  by a simple polynomial equation as follows :

propane :

$$\begin{aligned}\bar{\eta} - \eta_0 = & 2.286634 \times 10^3 \rho + 6.046793 \times 10^3 \rho^2 + 1.025224 \times 10^5 \rho^3 \\ & - 3.513343 \times 10^5 \rho^4 + 5.031422 \times 10^5 \rho^5\end{aligned}\quad (9)$$

propylene :

$$\begin{aligned}\bar{\eta} - \eta_0 = & 1.799455 \times 10^3 \rho + 2.744507 \times 10^4 \rho^2 + 9.993000 \times 10^3 \rho^3 \\ & - 1.784859 \times 10^5 \rho^4 + 3.364024 \times 10^5 \rho^5\end{aligned}\quad (10)$$

where

$\bar{\eta}$  = weighted mean value or smoothed value of viscosity in  $10^{-8}$  Pa·s,

$\eta_0$  = viscosity at the normal pressure in  $10^{-8}$  Pa·s calculated by Eq. (1) for propane and Eq. (3) for propylene.

$\rho$  = density in  $\text{g}\cdot\text{cm}^{-3}$ .

The values of density were calculated from the recommended values of the compressibility factor presented by this Committee<sup>27)</sup> previously. These correlations can be used in the range of density between about 0.05 and 0.53  $\text{g}\cdot\text{cm}^{-3}$  with the estimated mean deviations of 2% for propane and 4% for propylene except narrow regions near the critical point.

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