A Correlation of the Viscosity and Thermal Conductivity Data of Gaseous and Liquid Ethylene

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Data for the viscosity and thermal conductivity coefficient of gaseous and liquid ethylene have been evaluated and represented by an empirical function, developed in previous work. Tables of values are presented for the range 110–500 K for pressures to 50 MPa (≈500 atm). Both the viscosity and thermal conductivity coefficients are estimated to have uncertainties of about ± 5% increasing to 10% in the dense liquid. It is stressed that the data base could be improved. As in our work with other fluids, the anomalous contribution to the thermal conductivity in the vicinity of the critical point is included.

Key words: critical point enhancement; correlated data; data evaluation; ethylene; thermal conductivity coefficient; viscosity coefficient.

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Nomenclature

T	temperature
P	pressure
K_T	compressibility
ρ	mass density
η	viscosity coefficient
η_0	dilute gas viscosity
η_1	viscosity first density correction
$\Delta\eta$	excess viscosity
$\Delta\eta'$	dense gas and liquid viscosity

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$\Delta\eta_c$ critical region excess viscosity
$j_i(i = 1,7),E$ viscosity equation parameters
$GV(i)(i = 1,9)$ dilute gas viscosity equation parameters
λ thermal conductivity coefficient
λ_0 dilute gas thermal conductivity
λ_1 thermal conductivity first density correlation
$\Delta\lambda$ excess thermal conductivity
$\Delta\lambda'$ dense gas and liquid thermal conductivity
$\Delta\lambda_c$ critical region excess thermal conductivity
$k_i(i = 1,7),D$ thermal conductivity equation parameters
$GT(i)(i = 1,9)$ dilute gas thermal conductivity equation parameters
M molecular weight
N_A Avogadro constant
k Boltzmann constant
Φ intermolecular pair potential
$m,\gamma',\sigma,r_m,d,\epsilon$ potential parameters
A,B,C,F first density correction equation parameters
θ viscosity and thermal conductivity equation variable
$*$ reduced variable superscript
c critical point variable subscript
$x_0,\beta,E_1,E_2,\delta,\gamma$ scaling parameters for the compressibility in the critical region
R length parameter in the critical point equation
also x, χ_T, B, Γ, ξ, ξ_0, ν, $h(x)$, ΔT^*, $\Delta\rho^*$, T_c, ρ_c, F used in Eqs. (10)–(19) for the critical enhancement.

1. Introduction

We have published several papers in this journal on the viscosity and thermal conductivity of pure fluids including ethane[1] and propane.[2] The purpose of this paper is to correlate the available viscosity (η) and thermal conductivity (λ) coefficient data of ethylene and to present tables of values of a range of pressure (P) and temperature (T): specifically, pressures to 50 MPa and temperatures between 110 and 500 K.

Ethylene is a common and industrially important fluid. There is a need for a correlation since previous work generally covers only a limited experimental range and/or discusses only one of the coefficients.[3] Also the equation of state and the thermodynamic properties of ethylene have recently been studied in depth[4] so a transport correlation is a timely adjunct to this latter work. Unfortunately, as is so often the case for all but the simplest fluids, data that are both reliable and cover a wide range of experimental conditions are not available. Several authors have pointed out that new measurement techniques have led to a renewed interest in transport properties but much of the data for ethylene is old and, although data should not be judged solely on their age, cannot in general be considered authoritative by the standards of the last ten years or so.

The viewpoint of this work is to examine the available transport data and correlate them based on our experience with previous fluids. The procedure and the correlating functions introduced in Ref. 5 will be used. The tables are presented with the reservation that they will have to be revised when more accurate and wide-ranged data become available and that the functions themselves should be reexamined. (We do remark, however, that it is convenient for a user to have a given set of functions applicable to many fluids, even at the risk of some overfitting of the data.) The discussion here is abbreviated since it follows that of Refs. 1 and 2 very closely, and we refer to Ref. 5 for details of the criteria applied to evaluate the data critically.

2. Correlating Equations

The correlation for ethylene was based on the behavior[6] of the transport coefficients with respect to temperature (T) and density (ρ) according to the equations

$$\eta(\rho,T) = \eta_0(T) + \eta_1(T)\rho + \Delta\eta'(\rho,T) + \Delta\eta_c(\rho,T), \quad (1)$$

$$\lambda(\rho,T) = \lambda_0(T) + \lambda_1(T)\rho + \Delta\lambda'(\rho,T) + \Delta\lambda_c(\rho,T), \quad (2)$$

for the viscosity and thermal conductivity, respectively. In these equations, $\eta_0(T)$ and $\lambda_0(T)$ are the dilute gas values; $\eta_1(T)$ and $\lambda_1(T)$ represent first density corrections for the moderately dense gas; while $\Delta\eta'(\rho,T)$ and $\Delta\lambda'(\rho,T)$ are remainders. The term $\eta_1(T)$ is given by the empirical expression

$$\eta_1(T) = A + B[C - \ln(T/F)]^2 \quad (3)$$

and similarly for $\lambda_1(T)$. The coefficients A, B, C, and F can be found from a fit of data, but we set $F = \epsilon/k$, where ϵ is the energy parameter of the ethylene pair potential function (see Sec. 3.1) and k is Boltzmann's constant.

The terms $\Delta\eta'(\rho,T)$ and $\Delta\lambda'(\rho,T)$ are expressed empirically by the relations

$$\Delta\eta'(\rho,T) = E\exp[j_1 + j_4/T]\{\exp[\rho^{0.1}(j_2 + j_3/T^{3/2}) + \theta\rho^{0.5}(j_5 + j_6/T + j_7/T^2)] - 1.0\}, \quad (4)$$

and

$$\Delta\lambda'(\rho,T) = D\exp[k_1 + k_4/T]\{\exp[\rho^{0.1}(k_2 + k_3/T^{3/2}) + \theta\rho^{0.5}(k_5 + k_6/T + k_7/T^2)] - 1.0\}. \quad (5)$$

The parameter θ is included to account specifically for the high density behavior of the transport coefficients and is a function of the density with respect to the critical density ρ_c:

$$\theta = (\rho - \rho_c)/\rho_c. \quad (6)$$

The coefficients, E, D, j_1, ..., j_7, k_1, ..., k_7, are obtained from experimental data.

Finally, Eqs. (1) and (2) include the terms $\Delta\eta_c(\rho,T)$ and $\Delta\lambda_c(\rho,T)$, respectively, to account for the known enhancement of the coefficients in the vicinity of the critical point (although $\Delta\eta_c$ will be set equal to zero in this work).

2.1. The Equation of State

As discussed in our previous work, the Eqs. (1)–(6) introduce the density: the data are thus correlated as a function of temperature and density rather than the perhaps more convenient variables temperature and pressure. The equation of state is an integral part of the correlation and that used here is the recent modified Benedict–Webb–Rubin (MBWR) discussed in full in Refs. 4 and 7. The form of the

MBWR and values for its parameters are given in the appendix.

3. Data

A search of the literature yielded the following references which reported experimental data; excluding some fragmentary or very incomplete results they are Refs. 8–32 for the viscosity and Refs. 33–52 for the thermal conductivity. The papers were evaluated by the procedure discussed in Ref. 5, namely, we relied strongly on the following: a check of the density (if it is reported) via the MBWR equation of state given the pressure and temperature; an extrapolation of dense gas and liquid data to the dilute gas limit and a subsequent comparison with selected dilute gas data (see Sec. 3.1); a plot of the excess functions $\Delta\eta(\rho,T)$ and $\Delta\lambda(\rho,T)$ versus density. The excess function is defined by $\Delta\eta(\rho,T) = \eta(\rho,T) - \eta_0(T)$ and similarly for the thermal conductivity. It has been shown to be a significant quantity in that it reveals discrepancies between authors and discrepancies within a given data set, and provides a check on the anticipated temperature and density dependence of the coefficients. We also relied on subjective criteria based on our experience with fluids other than ethylene: (1) how the author compares with modern data, (2) how our functional forms Eqs. (3)–(5) fit the data. Since these forms have worked for many fluids, it would be expected that they would also work for ethylene, and (3) if the author's estimate of accuracy was consistent with ours. Of course the bias in this argument is realized but we feel it is a workable procedure until further data become available.

As in our previous work, we consider the dilute gas, the dense gas and liquid, and the critical region separately.

3.1. The Dilute Gas

The data of Kestin *et al.*[8,13] are considered authoritative and are estimated to have an accuracy of $\pm 0.3\%$ and formed the basis of the dilute viscosity fit. They cover the range 296–477 K but we have extended this range slightly by including adjusted data of Trautz *et al.*[10–12] following the procedure of Ref. 5. The data, Table 1, were then fitted to the functional form

$$\eta_0 = GV(1)T^{-1} + GV(2)T^{-2/3} + GV(3)T^{-1/3} + GV(4) + GV(5)T^{1/3} + GV(6)T^{2/3} + GV(7)T + GV(8)T^{4/3} + GV(9)T^{5/3}, \quad (7)$$

TABLE 1. Selected references for ethylene

Authors	Approximate experimental range
Viscosity—Dilute gas	
Kestin *et al.* (Refs. 8 and 13)	296–477 K
Trautz *et al.* (Refs. 10–12)	194–525 K
Viscosity—Dense gas and liquid	
Comings *et al.* (Refs. 21 and 22)	303–368 K Pressures to 17.3 MPa
Felsing and Blankenship (Ref. 23)	303–323 K Pressures to 18.6 MPa
Golubev *et al.* (Refs. 14 and 25)	297–423 K Pressures to 81.1 MPa
Neduzhii and Khmara (Ref. 15)	193–297 K Pressures to 3.9 MPa
Rudenko (Ref. 31)	111–168 K Saturated liquid
Gerf and Galkov (Refs. 27 and 28)	105–252 K Saturated liquid
Thermal conductivity—Dilute gas	
Several authors (Refs. 33–49)	180–673 K
Thermal conductivity—Dense gas and liquid	
Lenoir and Comings (Ref. 43)	314–340 K Pressures to 22.9 MPa
Keyes (Ref. 44)	345–426 K Pressures to 1.5 MPa
Neduzhii *et al.* (Ref. 46)	250–400 K Pressures to 4.0 MPa
Kolomiets (Ref. 47)	180–480 K Pressures to 50.0 MPa
Borovik (Ref. 51)	171 K Pressures to 5.3 MPa
Borovik (Ref. 50)	113–273 K Saturated liquid

where $GV(1)$, ..., $GV(9)$ are empirical coefficients. A deviation plot is shown in Fig. 1, where in this figure (and elsewhere) we give the percent deviation as

$$\frac{\eta(\text{exp}) - \eta(\text{calc})}{\eta(\text{exp})} \times 100. \quad (8)$$

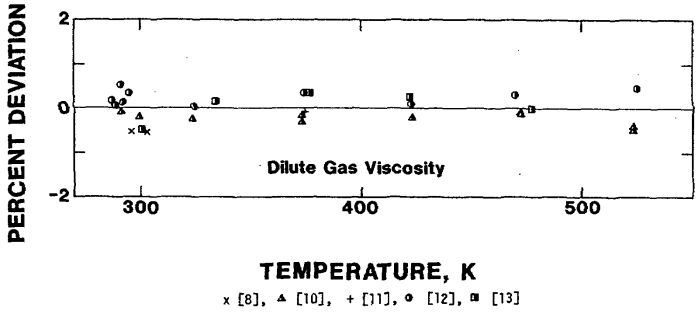

FIGURE 1. Deviation plot between dilute gas viscosity data and values calculated from Eq. (7).

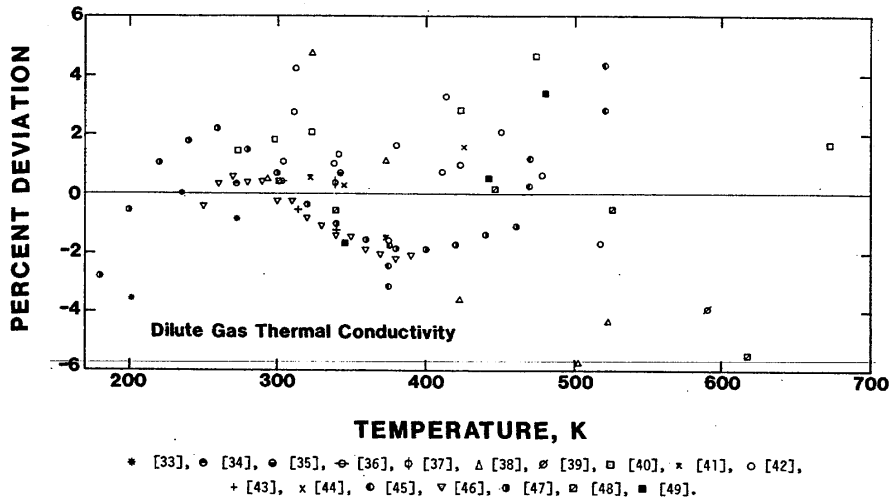

FIGURE 2. Deviation plot between dilute gas thermal conductivity data and values calculated from Eq. (9).

To ensure that the function form can be extrapolated to reasonable values, several theoretical points from 150 to 258 K and from 600 to 1200 K were included in the fit. These theoretical points were obtained from kinetic theory with the m-6-8 potential function and were considered only to ensure that the function (7) is well behaved outside the data range. The m-6-8 potential is given by the expression

$$\frac{\Phi(r^*)}{\epsilon} = \frac{1}{m-6}[6+2\gamma'](d/r^*)^m - \frac{1}{m-6}[m-\gamma'(m-8)](d/r^*)^6 - \gamma'(d/r^*)^8,$$

where $d = r_m/\sigma$ and $r^* = r/\sigma$. The distance parameters σ and r_m, and the energy parameter, ϵ, are defined by the relationships $\Phi(r_m) = -\epsilon$ and $\Phi(\sigma) = 0$ while γ' is a parameter representing inverse eighth attraction in the potential. Parameter values are in Table 4. One observes the fit of Fig. 1 is to within about $\pm 0.5\%$.

Several authors have reported dilute gas thermal conductivity data but no one set can be considered definitely superior. Consequently data from Refs. 33–49 were used and fitted with equal weight to the equation corresponding to equation (7):

$$\lambda_0 = GT(1)T^{-1} + GT(2)T^{-2/3} + GT(3)T^{-1/3} + GT(4) + GT(5)T^{1/3} + GT(6)T^{2/3} + GT(7)T + GT(8)T^{4/3} + GT(9)T^{5/3}, \quad (9)$$

TABLE 2. Parameters for the dilute gas Eqs. (7) and (9). The units are temperature in K, viscosity in 10^{-7} Pa·s, and thermal conductivity in mW/(m·K)

$GV(1) =$	$-3.509\,822\,501\,8\times10^{6}$	$GT(1) =$	$-2.903\,423\,528\,0\times10^{5}$
$GV(2) =$	$2.500\,840\,618\,4\times10^{6}$	$GT(2) =$	$4.680\,624\,952\,0\times10^{5}$
$GV(3) =$	$-5.836\,554\,074\,4\times10^{5}$	$GT(3) =$	$-1.895\,478\,321\,5\times10^{5}$
$GV(4) =$	$4.554\,914\,658\,3\times10^{3}$	$GT(4) =$	$-4.826\,223\,539\,2\times10^{3}$
$GV(5) =$	$2.288\,168\,340\,3\times10^{4}$	$GT(5) =$	$2.243\,409\,372\,0\times10^{4}$
$GV(6) =$	$-4.731\,868\,207\,7\times10^{3}$	$GT(6) =$	$-6.620\,635\,481\,8\times10^{3}$
$GV(7) =$	$4.502\,224\,925\,8\times10^{2}$	$GT(7) =$	$8.993\,771\,707\,8\times10^{2}$
$GV(8) =$	$-2.149\,068\,808\,8\times10^{1}$	$GT(8) =$	$-6.055\,914\,371\,8\times10^{1}$
$GV(9) =$	$4.164\,926\,323\,3\times10^{-1}$	$GT(9) =$	$1.637\,030\,642\,2$

The deviation curve is given in Fig. 2 and differences between Eq. (9) and experiment are generally within $\pm 4\%$. Notice, however, that data from several sets show systematic temperature deviations and generally are imprecise to $\pm 2\%$. We used the Euken expression to estimate semiempirically points between 120 and 200 K to ensure that the function (9) was well behaved. The data selected are summarized in Table 1 and the coefficients of Eqs. (7) and (9) listed in Table 2.

3.2. The Dense Gas and Liquid

Given η_0 and λ_0 and the equation of state, excess-density plots of the dense gas and liquid data were constructed.[6]

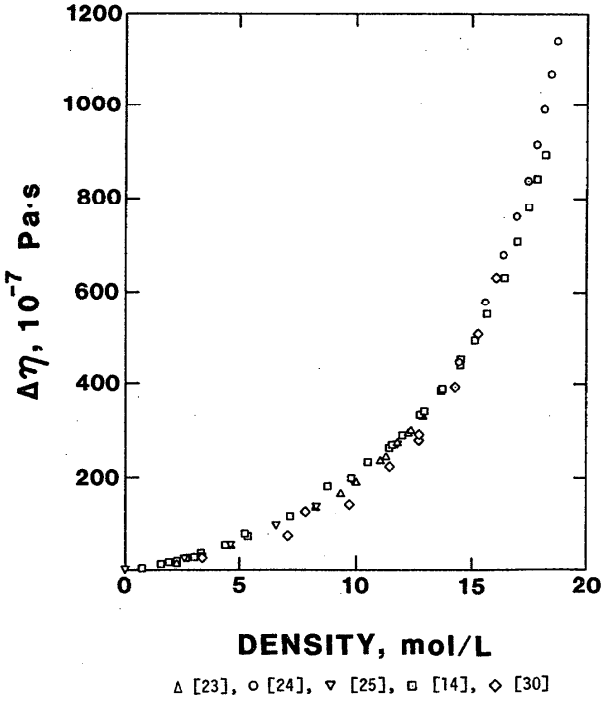

FIGURE 3. Plot of the excess viscosity coefficient vs density.

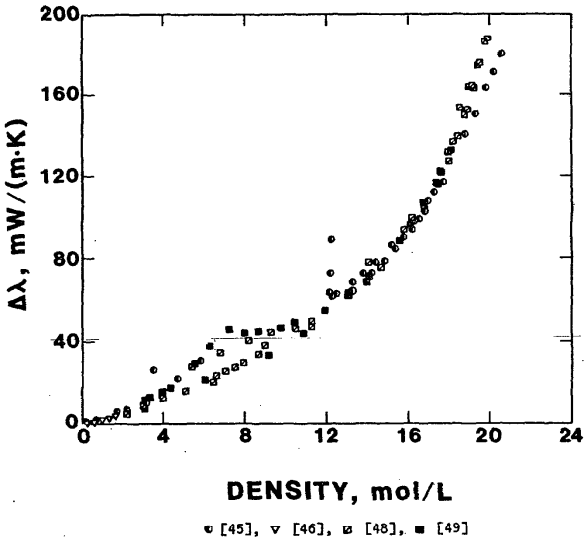

FIGURE 4. Plot of the excess thermal conductivity coefficient vs density. Note the apparent anomaly around the critical density. Convection may play a role here, however.

Representative points are shown in Figs. 3 and 4. We have excluded points which are clearly erroneous and some points around the critical region. The curves show clearly the discrepancies between the data of the various authors. Using the criteria mentioned at the beginning of Sec. 3, we selected the data listed in Table 1 for fitting. The temperature and pressure ranges are shown for convenience.

The resulting values of the coefficients for Eqs. (3), (4),

TABLE 3. Parameters for Eqs. (3)–(5). Units: Temperature in K, viscosity in 10^{-7} Pa·s, and thermal conductivity in mW/(m·K)

Viscosity	
Eq. (3)	$A = B = C = 0.0, F = 358.9$
Eq. (4)	$E = 1.0$
	$j_1 = -4.854\,448\,673\,2$
	$j_2 = 1.303\,358\,523\,6 \times 10^{1}$
	$j_3 = 2.780\,892\,890\,8 \times 10^{4}$
	$j_4 = -1.824\,197\,130\,8 \times 10^{3}$
	$j_5 = 1.591\,302\,450\,9$
	$j_6 = -2.051\,357\,392\,7 \times 10^{2}$
	$j_7 = -3.947\,845\,470\,8 \times 10^{4}$
Thermal conductivity	
Eq. (3)	$A = B = C = 0.0, F = 358.9$
Eq. (5)	$D = 1.0$
	$k_1 = -1.304\,503\,323\,0 \times 10^{1}$
	$k_2 = 1.821\,461\,659\,9 \times 10^{1}$
	$k_3 = 9.903\,022\,496\,0 \times 10^{3}$
	$k_4 = 7.420\,521\,631\,0 \times 10^{2}$
	$k_5 = -3.008\,327\,193\,3 \times 10^{-1}$
	$k_6 = 9.645\,606\,882\,9 \times 10^{1}$
	$k_7 = 1.350\,256\,962\,0 \times 10^{4}$

TABLE 4. Critical point parameters, m-6-8 potential function parameters, and parameters for Eq. (16) for ethylene

Critical point constants	
T_c	$= 282.34$ K
ρ_c	$= 0.215$ g/cm^3 (7.66 mol/L)
P_c	$= 5.0390$ MPa (49.73 atm)
M	$= 28.054$
m-6-8 parameters	
ϵ/k	$= 269$ K
σ	$= 3.68 \times 10^{-10}$ m
r_m	$= 4.10 \times 10^{-10}$ m
γ'	$= 3.0$
m	$= 11$
Parameters for Eq. (16)	
E_1	$= 2.17$
E_2	$= 0.287$
x_0	$= 0.168$
β	$= 0.355$
γ	$= 1.190$

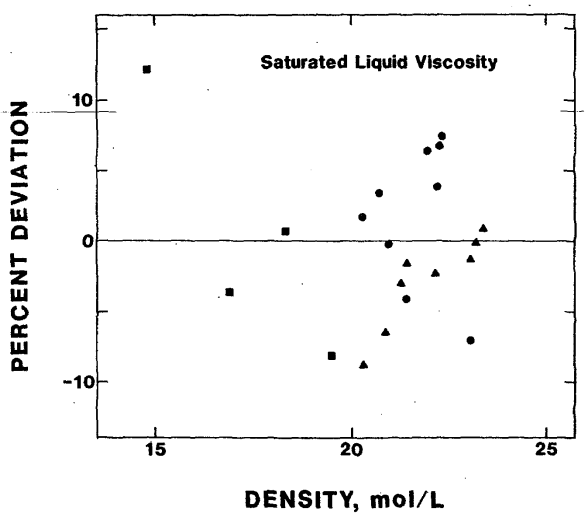

FIGURE 5. Deviation plot for the viscosity coefficient at saturated liquid boundary.

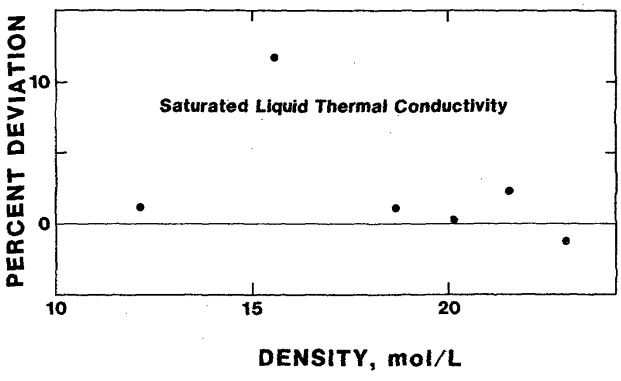

FIGURE 6. Deviation plot for the thermal conductivity coefficient at saturated liquid boundary.

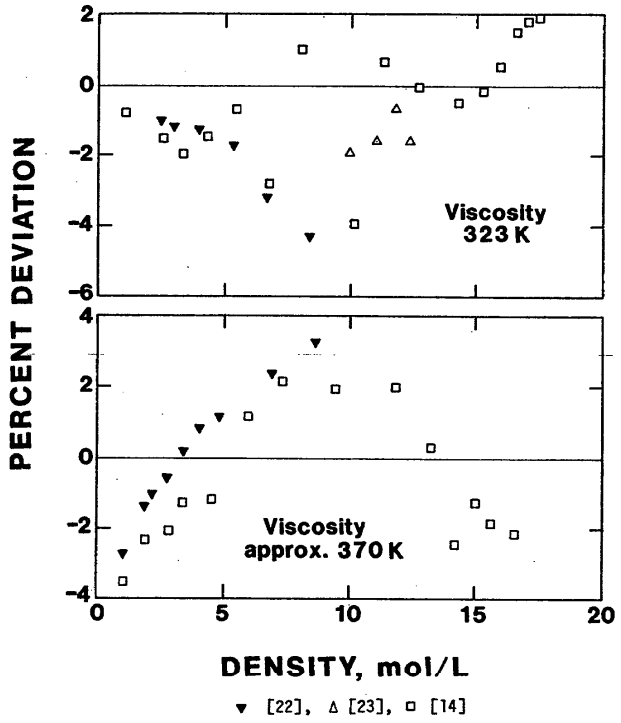

FIGURE 7. Deviation plots for the viscosity coefficient: top, 323 K data; bottom, approximately 370 K data.

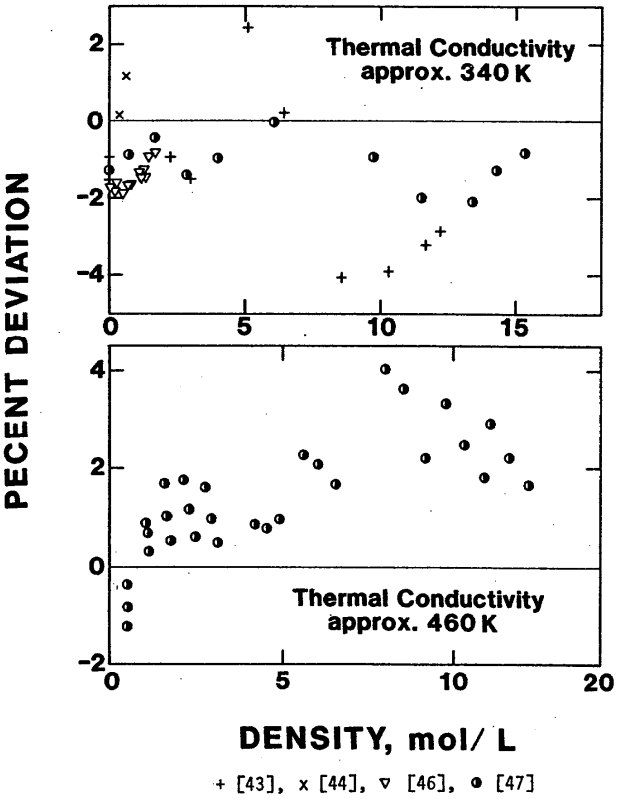

FIGURE 8. Deviation plots for the thermal conductivity coefficient: top, approximately 340 K data; bottom, approximately 460 K data.

and (5) are shown in Table 3 with the value of ρ_c given in Table 4. Deviation plots for the saturated liquid are shown in Figs. 5 and 6 with similar plots for the dense gas at various temperatures given in Figs. 7 and 8. Qualitatively, the data chosen seem to be reasonable with no serious discrepancies between the selected data sets. However it should be pointed out that at temperatures below about 200 K and at pressures greater than about 20 MPa the data of only a few authors are represented. In addition below 200 K most of the selected data are more than 40 years old.

3.3. The Critical Region

As remarked earlier, Eqs. (1) and (2) contain contributions due to the enhancement of the viscosity and thermal conductivity in the region of the critical point. The anomalies are well established[53] but one can argue that the viscosity enhancement is small unless the fluid is very close to critical and can be neglected for practical purposes for all but the most authoritative correlation of precise data. We do indeed neglect it here and refer to the paper of Basu and Sengers[54] for a discussion and prescription on the evaluation of $\Delta\eta_c$. The thermal conductivity enhancement is included but we prefer to estimate it by calculation, as in previous publications, since the ethylene data in the critical region are sparce and most probably affected by convection.[49] First, an outline of some background is necessary.

The critical region is associated with large spontaneous fluctuations in the density which are responsible for the special behavior of a fluid around the critical point and these fluctuations can be described in terms of a distance parameter ξ which is the range of the pair correlation function: ξ approaches infinity as the critical point is approached. Modern theory rests on the results that ξ is much larger than the effective range of the intermolecular forces and hence details of the latter do not affect the nature of the critical anomalies. The principle of three scale factor universality, discussed by Sengers and co-workers,[53,55] states that the equation of state in the critical region is completely determined by universal quantities, except for the system dependent scale factors B, Γ, and ξ_0. These are related, respectively, to the variation of density with temperature at coexistence, with the compressibility along the critical isochore, and with length. Defining

$$\Delta\rho^* = \left(\frac{\rho-\rho_c}{\rho_c}\right), \quad \Delta T^* = \left(\frac{T-T_c}{T_c}\right),$$

and

$$\chi_T^* = \rho^2 K_T P_c/\rho_c^2, \tag{10}$$

where K_T is the isothermal compressibility, one has for parameter B:

$$\Delta\rho^* = \pm B\,|\Delta T^*|^\beta \quad \text{or} \quad B = x_0{}^{-\beta}, \tag{11}$$

where in general $x = |\Delta T^*|/|\Delta\rho^*|^{1/\beta}$ and $x = -x_0$ at coexistence. The parameter Γ is defined via

$$\chi_T^* = \Gamma\,|\Delta T^*|^{-\gamma}, \tag{12}$$

and the length parameter by

$$\xi = \xi_0|\Delta T^*|^{-\nu} \equiv \xi_0(\chi_T^*/\Gamma)^{\nu/\gamma}. \tag{13}$$

The exponents β and γ are universal with values $\beta = 0.355$

and $\gamma = 1.19$ [ν is not independent and defined by $\nu = (2\beta + \gamma)/3$].

Further, Sengers and Moldover[55] argue that the three scale factors can be reduced to two according to the interrelation

$$\xi_0 (B^2 p_c / \Gamma k T_c)^{1/2} = R, \tag{14}$$

where R is a universal constant ≈ 0.69.

One further remark is required: an analytical equation of state such as the MBWR used here cannot represent the compressibility correctly close to the critical point. Accordingly if $|\Delta\rho^*| \leqslant 0.25$ and $|\Delta T^*| \leqslant 0.025$ we switch to the scaled equation

$$\chi_T^{*-1} = |\Delta\rho^*|^{\gamma/\beta} \left[h(x) - \frac{x}{\beta} h'(x) \right], \tag{15}$$

where $h'(x) = dh(x)/dx$ with x defined via Eq. (11). The equation for the function $h(x)$ is that of Vicentini *et al.*[56]:

$$h(x) = E_1 \left(\frac{x + x_0}{x_0} \right) \left[1 + E_2 \left(\frac{x + x_0}{x_0} \right)^{2\beta} \right]^{[(\gamma - 1)/2\beta]}, \tag{16}$$

where E_2 is a universal constant of value 0.287. Hence the scale factors B, Γ, and ξ_0 follow: B from Eq. (11), Γ from Eqs. (12) and (15) which gives

$$\Gamma = x_0^{\gamma} / [E_1 E_2^{(\gamma - 1)/2\beta}]. \tag{17}$$

Having B and Γ, the length parameter ξ_0 can be evaluated from Eq. (14).

3.3.a. Thermal Conductivity

The equation for $\Delta\lambda_c$ is as before:

$$\Delta\lambda_c = \left(\frac{m}{\rho N_A k T} \right)^{1/2} \frac{k T^2}{6\pi\eta\xi} \left(\frac{\partial p}{\partial T} \right)_\rho^2 (K_T)^{1/2} F(\Delta T^*, \Delta\rho^*), \tag{18}$$

and we refer to Refs. 53 and 57 for details on its derivation. $F(\Delta T^*, \Delta\rho^*)$ is a factor to ensure $\Delta\lambda_c$ damps smoothly from the critical point[57]:

$$F(\Delta T^*, \Delta\rho^*) = \exp(-18.66 \Delta T^{*2}) \exp(-4.25 \Delta\rho^{*4}). \tag{19}$$

where the constants come from our earlier work.[5,57] We assume they are universal but more recent studies indicate they are a weak characteristic of the fluid.[54]

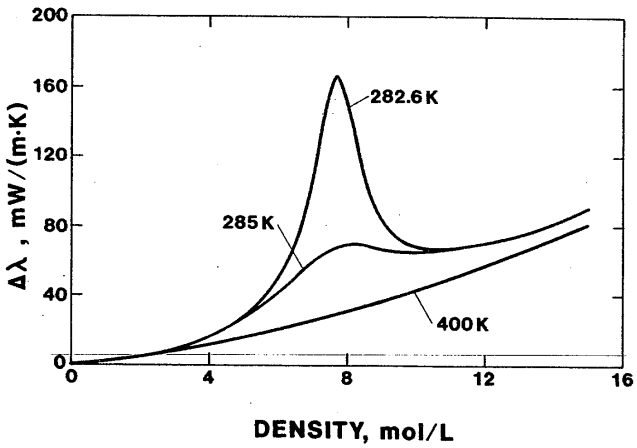

FIGURE 9. Plot of the calculated critical enhancement to the thermal conductivity coefficient for three isotherms. We have plotted the excess $\Delta\lambda(\rho,T) = \lambda(\rho,T) - \lambda_0(T)$ using Eqs. (2) and (18).

To illustrate graphically the effect of the critical point on the conductivity, we constructed Fig. 9 giving three sample isotherms, 282.6, 285, and 400 K for the excess $\Delta\lambda$ calculated from Eq. (2) incorporating Eq. (18). This figure also illustrates the $(\partial\Delta\lambda/\partial T)_\rho$ appears to be negative at high densities. This observation was unexpected and is contrary to the behavior observed for the fluids previously studied.[6]

4. Tables of Values

The viscosity and thermal conductivity coefficients of ethylene have been calculated for 110–500 K for pressures up to 50 MPa ($\approx$500 atm). Tabular values are presented as Tables 5 and 6. We ensured that an entry in the table would not require an extrapolation much beyond the range of data. Blanks in the tables indicate that the P–T points correspond to densities exceeding 23.3 mol/L, the upper density limit for the data for temperatures less than 300 K, or 15.1 mol/L for the higher temperatures. For convenience, saturated liquid values have been listed separately as Table 7 and dilute gas values as Table 8. (The tables contain more significant figures than the accuracy of the data warrant. The extra figures are given to facilitate reproduction and interpolation of the tables.)

Table 5. Viscosity of ethylene. Units: 10^{-7} Pa.s

T,K \ P,MPa	.1	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
110.0	5660.5	5645.9	5627.6	5609.4	5591.3	5573.2	5555.1	5537.0	5519.0	5501.0	5483.1
115.0	4918.5	4907.7	4894.3	4880.8	4867.4	4854.1	4840.8	4827.5	4814.3	4801.1	4787.9
120.0	4307.2	4298.9	4288.7	4278.4	4268.2	4258.1	4247.9	4237.8	4227.8	4217.8	4207.8
125.0	3807.8	3801.3	3793.4	3785.4	3777.5	3769.6	3761.7	3753.9	3746.1	3738.4	3730.6
130.0	3398.3	3393.3	3387.0	3380.8	3374.6	3368.4	3362.2	3356.1	3349.9	3343.9	3337.8
135.0	3059.7	3055.8	3050.8	3045.9	3041.0	3036.2	3031.3	3026.5	3021.7	3016.9	3012.1
140.0	2776.8	2773.6	2769.8	2765.9	2762.1	2758.3	2754.4	2750.7	2746.9	2743.1	2739.4
145.0	2537.4	2535.0	2532.0	2529.1	2526.1	2523.1	2520.2	2517.2	2514.3	2511.4	2508.5
150.0	2332.7	2330.9	2328.6	2326.4	2324.1	2321.9	2319.7	2317.4	2315.2	2313.1	2310.9
155.0	2155.4	2154.1	2152.5	2150.9	2149.3	2147.7	2146.1	2144.5	2142.9	2141.3	2139.8
160.0	2000.3	1999.5	1998.4	1997.4	1996.3	1995.2	1994.2	1993.1	1992.1	1991.1	1990.0
165.0	1863.2	1862.7	1862.2	1861.6	1861.0	1860.5	1859.9	1859.4	1858.8	1858.2	1857.7
170.0	60.5	1740.6	1740.5	1740.4	1740.3	1740.2	1740.1	1740.0	1739.9	1739.8	1739.6
175.0	62.2	1630.7	1631.0	1631.4	1631.7	1632.0	1632.3	1632.6	1632.8	1633.1	1633.4
180.0	63.8	1530.9	1531.6	1532.3	1533.0	1533.7	1534.4	1535.1	1535.8	1536.4	1537.0
185.0	65.4	1439.6	1440.7	1441.8	1442.9	1444.0	1445.0	1446.0	1447.1	1448.1	1449.0
190.0	67.0	1355.6	1357.1	1358.5	1359.9	1361.4	1362.8	1364.1	1365.5	1366.8	1368.1
195.0	68.6	1277.7	1279.5	1281.3	1283.1	1284.9	1286.6	1288.3	1290.0	1291.7	1293.3
200.0	70.2	1205.1	1207.3	1209.4	1211.6	1213.7	1215.7	1217.8	1219.8	1221.8	1223.7
205.0	71.8	73.1	1139.5	1142.0	1144.5	1146.9	1149.4	1151.7	1154.1	1156.4	1158.6
210.0	73.4	74.6	1075.5	1078.4	1081.3	1084.1	1086.9	1089.6	1092.2	1094.9	1097.5
215.0	75.1	76.2	1014.8	1018.1	1021.3	1024.5	1027.7	1030.7	1033.8	1036.7	1039.7
220.0	76.7	77.8	956.6	960.4	964.1	967.7	971.3	974.7	978.1	981.5	984.7
225.0	78.4	79.4	81.8	904.9	909.1	913.2	917.2	921.1	924.9	928.6	932.3
230.0	80.1	81.1	83.2	851.1	855.9	860.5	865.0	869.4	873.6	877.8	881.9
235.0	81.7	82.7	84.7	88.0	803.8	809.1	814.2	819.1	823.9	828.6	833.2
240.0	83.4	84.4	86.3	89.2	752.3	758.4	764.3	769.9	775.4	780.6	785.8
245.0	85.1	86.0	87.8	90.6	94.8	707.9	714.7	721.2	727.5	733.5	739.3
250.0	86.8	87.7	89.4	91.9	95.7	656.6	664.8	672.5	679.8	686.7	693.3
255.0	88.5	89.4	91.0	93.4	96.7	101.9	613.5	622.8	631.5	639.7	647.4
260.0	90.2	91.1	92.7	94.8	97.9	102.3	109.5	570.9	581.8	591.7	600.9
265.0	91.9	92.8	94.3	96.4	99.2	103.0	108.8	514.1	528.8	541.5	552.9
270.0	93.6	94.5	95.9	97.9	100.5	104.0	108.9	116.6	468.2	486.7	502.0
275.0	95.3	96.2	97.6	99.5	101.9	105.0	109.3	115.4	125.8	419.8	444.5
280.0	97.0	97.9	99.2	101.0	103.3	106.2	110.0	115.2	122.8	137.0	365.4
285.0	98.7	99.6	100.9	102.6	104.8	107.5	110.9	115.4	121.5	131.0	149.8
290.0	100.4	101.2	102.6	104.2	106.3	108.8	111.9	115.9	121.1	128.4	139.6
295.0	102.1	102.9	104.2	105.8	107.8	110.1	113.0	116.6	121.2	127.2	135.5
300.0	103.8	104.6	105.9	107.4	109.3	111.5	114.2	117.5	121.6	126.7	133.4

Table 5. Viscosity of ethylene. Units: 10^{-7} Pa·s--Continued

T \ P	6.0	7.0	8.0	9.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0
110.0	5447.3	5411.6	5376.1	5340.6	5305.3						
115.0	4761.7	4735.6	4709.7	4683.9	4658.3	4532.0	4408.7	4287.9			
120.0	4187.9	4168.2	4148.5	4129.1	4109.7	4014.8	3922.7	3833.2	3746.0		
125.0	3715.2	3700.0	3684.8	3669.7	3654.8	3581.7	3511.1	3442.8	3376.5	3249.5	3128.8
130.0	3325.7	3313.8	3301.9	3290.2	3278.5	3221.5	3166.5	3113.4	3062.1	2964.2	2871.8
135.0	3002.6	2993.2	2983.9	2974.7	2965.5	2920.7	2877.7	2836.2	2796.1	2719.9	2648.0
140.0	2732.0	2724.6	2717.3	2710.1	2702.9	2667.8	2634.2	2601.7	2570.4	2510.8	2454.9
145.0	2502.8	2497.1	2491.4	2485.8	2480.3	2453.1	2427.0	2401.9	2377.6	2331.4	2288.0
150.0	2306.5	2302.2	2298.0	2293.7	2289.5	2269.0	2249.2	2230.1	2211.6	2176.4	2143.2
155.0	2136.6	2133.5	2130.4	2127.4	2124.3	2109.4	2095.0	2081.0	2067.4	2041.5	2016.8
160.0	1988.0	1985.9	1983.8	1981.8	1979.8	1969.8	1960.0	1950.4	1941.1	1923.1	1905.8
165.0	1856.6	1855.4	1854.3	1853.2	1852.0	1846.4	1840.7	1835.1	1829.5	1818.3	1807.4
170.0	1739.4	1739.1	1738.8	1738.5	1738.2	1736.4	1734.4	1732.2	1729.9	1725.0	1719.7
175.0	1633.9	1634.4	1634.9	1635.3	1635.7	1637.5	1638.9	1639.9	1640.5	1641.1	1640.9
180.0	1538.3	1539.5	1540.7	1541.8	1542.9	1548.0	1552.4	1556.3	1559.7	1565.3	1569.6
185.0	1451.0	1452.9	1454.7	1456.5	1458.2	1466.4	1473.6	1480.1	1486.0	1496.2	1504.8
190.0	1370.7	1373.3	1375.7	1378.1	1380.5	1391.5	1401.3	1410.3	1418.5	1433.0	1445.5
195.0	1296.5	1299.7	1302.8	1305.7	1308.7	1322.4	1334.7	1346.0	1356.3	1374.8	1390.8
200.0	1227.6	1231.3	1235.0	1238.5	1242.0	1258.3	1273.0	1286.4	1298.8	1320.9	1340.3
205.0	1163.1	1167.4	1171.7	1175.8	1179.8	1198.6	1215.5	1231.0	1245.3	1270.9	1293.4
210.0	1102.5	1107.5	1112.3	1116.9	1121.5	1142.7	1161.8	1179.3	1195.3	1224.2	1249.7
215.0	1045.4	1050.9	1056.3	1061.5	1066.6	1090.2	1111.4	1130.8	1148.6	1180.5	1208.8
220.0	991.1	997.3	1003.3	1009.1	1014.7	1040.7	1064.0	1085.1	1104.6	1139.5	1170.4
225.0	939.4	946.2	952.8	959.2	965.4	993.9	1019.2	1042.1	1063.1	1100.8	1134.2
230.0	889.8	897.3	904.6	911.6	918.4	949.4	976.7	1001.4	1023.9	1064.3	1100.0
235.0	841.9	850.3	858.3	866.0	873.4	907.0	936.4	962.7	986.7	1029.7	1067.7
240.0	795.5	804.8	813.6	822.0	830.1	866.5	897.9	925.9	951.4	996.9	1037.0
245.0	750.2	760.5	770.3	779.5	788.3	827.6	861.1	890.9	917.8	965.7	1007.8
250.0	705.7	717.2	728.0	738.2	747.8	790.2	825.9	857.3	885.7	935.9	980.1
255.0	661.6	674.6	686.6	697.8	708.4	754.1	792.1	825.2	855.0	907.5	953.6
260.0	617.4	632.3	645.8	658.2	669.8	719.2	759.5	794.4	825.6	880.3	928.2
265.0	572.8	590.0	605.3	619.2	632.0	685.4	728.2	764.8	797.4	854.3	904.0
270.0	526.8	547.3	564.9	580.6	594.8	652.6	697.9	736.3	770.3	829.4	880.8
275.0	478.4	503.6	524.2	542.1	558.0	620.7	668.7	708.9	744.2	805.4	858.5
280.0	425.0	458.1	483.0	503.7	521.6	589.8	640.4	682.4	719.1	782.3	837.0
285.0	358.8	409.1	440.6	465.0	485.4	559.6	613.1	656.9	694.9	760.2	816.4
290.0	244.6	353.3	396.3	425.8	449.3	530.4	586.7	632.3	671.6	738.8	796.6
295.0	172.9	284.9	348.8	385.9	413.3	502.0	561.2	608.5	649.1	718.2	777.5
300.0	156.5	219.3	297.7	345.0	377.4	474.5	536.6	585.7	627.5	698.4	759.0

Table 5. Viscosity of ethylene. Units: 10^{-7} Pa·s--Continued

T \ P	.1	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
300.0	103.8	104.6	105.9	107.4	109.3	111.5	114.2	117.5	121.6	126.7	133.4
310.0	107.2	108.0	109.2	110.7	112.4	114.4	116.8	119.6	123.0	127.0	131.9
320.0	110.5	111.3	112.5	113.9	115.5	117.4	119.5	122.0	124.9	128.2	132.2
330.0	113.8	114.6	115.8	117.1	118.6	120.4	122.4	124.6	127.1	130.0	133.3
340.0	117.1	117.9	119.0	120.3	121.8	123.4	125.2	127.3	129.6	132.1	135.0
350.0	120.3	121.1	122.2	123.5	124.9	126.4	128.2	130.1	132.2	134.5	137.0
360.0	123.5	124.3	125.4	126.7	128.0	129.5	131.1	132.9	134.8	137.0	139.3
370.0	126.7	127.5	128.6	129.8	131.1	132.5	134.1	135.7	137.6	139.5	141.7
380.0	129.8	130.7	131.7	132.9	134.2	135.5	137.0	138.6	140.3	142.2	144.2
390.0	132.9	133.8	134.8	136.0	137.2	138.6	140.0	141.5	143.1	144.9	146.7
400.0	136.0	136.8	137.9	139.0	140.3	141.5	142.9	144.4	145.9	147.6	149.3
410.0	139.1	139.9	141.0	142.1	143.3	144.5	145.9	147.3	148.8	150.3	152.0
420.0	142.1	142.9	144.0	145.1	146.2	147.5	148.8	150.1	151.6	153.1	154.7
430.0	145.0	145.9	147.0	148.1	149.2	150.4	151.7	153.0	154.4	155.8	157.4
440.0	148.0	148.9	149.9	151.0	152.1	153.3	154.6	155.8	157.2	158.6	160.1
450.0	150.9	151.8	152.8	153.9	155.0	156.2	157.4	158.7	160.0	161.3	162.8
460.0	153.8	154.7	155.7	156.8	157.9	159.1	160.3	161.5	162.8	164.1	165.5
470.0	156.7	157.6	158.6	159.7	160.8	161.9	163.1	164.3	165.5	166.8	168.2
480.0	159.5	160.4	161.5	162.5	163.6	164.7	165.9	167.1	168.3	169.6	170.9
490.0	162.3	163.2	164.3	165.3	166.4	167.5	168.7	169.8	171.1	172.3	173.6
500.0	165.1	166.0	167.1	168.1	169.2	170.3	171.4	172.6	173.8	175.0	176.2

T \ P	6.0	7.0	8.0	9.0	10.0	15.0	20.0	30.0	40.0	50.0
300.0	156.5	219.3	297.7	345.0	377.4	474.5	536.6			
310.0	145.8	170.1	213.7	265.6	307.3	422.5	490.2	586.6		
320.0	142.4	157.3	180.0	212.4	249.0	375.0	447.7	548.8		
330.0	141.5	152.4	167.3	187.5	212.8	333.1	409.3	514.1	593.7	
340.0	141.9	150.6	161.7	176.0	195.6	297.8	375.2	482.3	563.8	
350.0	143.0	150.3	159.3	170.2	183.4	270.0	345.6	453.6	536.2	606.6
360.0	144.6	150.9	158.4	167.4	177.9	249.1	320.4	427.7	510.9	582.2
370.0	146.5	152.1	158.6	166.2	174.9	234.1	299.5	404.7	487.8	559.7
380.0	148.6	153.6	159.4	166.0	173.5	223.6	282.6	384.4	466.9	538.8
390.0	150.8	155.4	160.7	166.5	173.1	216.4	269.2	366.5	447.9	519.6
400.0	153.2	157.4	162.2	167.5	173.4	211.4	258.7	351.0	430.8	502.0
410.0	155.6	159.6	164.0	168.9	174.2	208.1	250.6	337.7	415.5	485.9
420.0	158.1	161.8	166.0	170.5	175.4	205.9	244.5	326.2	401.8	471.2
430.0	160.6	164.2	168.1	172.3	176.8	204.7	239.8	316.5	389.6	457.8
440.0	163.2	166.6	170.2	174.2	178.4	204.2	236.4	308.3	378.9	445.6
450.0	165.8	169.0	172.5	176.2	180.2	204.2	233.9	301.4	369.4	434.6
460.0	168.4	171.5	174.8	178.4	182.2	204.6	232.2	295.7	361.0	424.7
470.0	171.0	174.0	177.2	180.6	184.2	205.3	231.1	291.0	353.7	415.8
480.0	173.6	176.5	179.6	182.8	186.3	206.2	230.5	287.1	347.3	407.7
490.0	176.2	179.0	182.0	185.1	188.4	207.4	230.3	283.9	341.8	400.5
500.0	178.8	181.6	184.4	187.5	190.6	208.8	230.5	281.4	337.0	394.1

Table 6. Thermal conductivity of ethylene. Units: mW/(m·K)

T,K \ P,MPa	.1	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
110.0	261.77	262.32	263.01	263.70	264.39	265.09	265.78	266.48	267.19	267.89	268.60
115.0	253.82	254.31	254.93	255.56	256.18	256.80	257.43	258.05	258.68	259.31	259.94
120.0	246.97	247.44	248.02	248.60	249.18	249.76	250.34	250.93	251.51	252.09	252.68
125.0	240.61	241.05	241.60	242.16	242.71	243.26	243.82	244.37	244.93	245.48	246.03
130.0	234.43	234.86	235.40	235.93	236.47	237.00	237.54	238.07	238.60	239.13	239.67
135.0	228.32	228.74	229.26	229.78	230.31	230.83	231.35	231.87	232.38	232.90	233.42
140.0	222.22	222.63	223.14	223.66	224.17	224.68	225.19	225.70	226.21	226.71	227.22
145.0	216.11	216.52	217.03	217.53	218.04	218.55	219.05	219.55	220.05	220.55	221.05
150.0	210.01	210.42	210.92	211.43	211.93	212.43	212.93	213.43	213.92	214.42	214.91
155.0	203.94	204.34	204.85	205.35	205.85	206.35	206.84	207.34	207.83	208.32	208.81
160.0	197.91	198.32	198.82	199.32	199.82	200.32	200.81	201.31	201.80	202.29	202.78
165.0	191.95	192.36	192.86	193.37	193.87	194.37	194.86	195.36	195.85	196.34	196.83
170.0	9.71	186.48	186.99	187.50	188.00	188.50	189.00	189.50	190.00	190.49	190.98
175.0	9.96	180.71	181.23	181.74	182.25	182.75	183.25	183.76	184.25	184.75	185.24
180.0	10.21	175.05	175.58	176.09	176.61	177.12	177.63	178.13	178.63	179.13	179.63
185.0	10.46	169.51	170.04	170.57	171.09	171.61	172.12	172.63	173.14	173.64	174.15
190.0	10.72	164.08	164.62	165.16	165.69	166.22	166.74	167.26	167.78	168.29	168.80
195.0	10.99	158.77	159.32	159.87	160.42	160.96	161.49	162.02	162.55	163.07	163.59
200.0	11.27	153.56	154.13	154.69	155.25	155.81	156.36	156.90	157.44	157.98	158.50
205.0	11.56	12.19	149.03	149.62	150.20	150.77	151.34	151.90	152.45	153.00	153.54
210.0	11.87	12.47	144.01	144.62	145.23	145.83	146.41	146.99	147.57	148.14	148.70
215.0	12.20	12.78	139.05	139.70	140.33	140.96	141.57	142.18	142.78	143.37	143.95
220.0	12.54	13.10	134.13	134.81	135.48	136.15	136.79	137.43	138.06	138.68	139.29
225.0	12.90	13.44	14.25	129.94	130.66	131.36	132.06	132.73	133.40	134.05	134.69
230.0	13.28	13.80	14.57	125.03	125.82	126.58	127.33	128.05	128.76	129.46	130.14
235.0	13.68	14.19	14.92	15.89	120.92	121.76	122.57	123.36	124.13	124.88	125.61
240.0	14.10	14.59	15.29	16.20	115.91	116.85	117.76	118.63	119.47	120.29	121.08
245.0	14.54	15.01	15.69	16.54	17.73	111.81	112.83	113.81	114.74	115.65	116.52
250.0	15.00	15.45	16.10	16.91	17.99	106.59	107.76	108.87	109.93	110.94	111.90
255.0	15.48	15.92	16.54	17.31	18.31	19.75	102.57	103.84	105.03	106.16	107.24
260.0	15.97	16.40	17.00	17.73	18.66	19.94	22.07	98.80	100.14	101.40	102.60
265.0	16.49	16.90	17.48	18.18	19.05	20.20	21.93	93.95	95.44	96.82	98.11
270.0	17.02	17.42	17.98	18.65	19.47	20.53	22.00	24.49	91.16	92.64	94.01
275.0	17.57	17.96	18.50	19.14	19.92	20.90	22.20	24.16	27.98	88.92	90.37
280.0	18.14	18.51	19.04	19.65	20.39	21.30	22.48	24.12	26.78	32.80	86.91
285.0	18.72	19.09	19.59	20.19	20.89	21.74	22.81	24.24	26.34	29.93	38.84
290.0	19.32	19.67	20.16	20.73	21.41	22.21	23.20	24.47	26.22	28.85	33.47
295.0	19.93	20.27	20.75	21.30	21.94	22.70	23.62	24.77	26.28	28.38	31.58
300.0	20.56	20.89	21.35	21.88	22.50	23.22	24.08	25.13	26.46	28.23	30.69

Table 6. Thermal conductivity of ethylene. Units: mW/(m·K)--Continued

T \ P	6.0	7.0	8.0	9.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0
110.0	270.02	271.46	272.90	274.36	275.83						
115.0	261.21	262.47	263.75	265.03	266.31	272.83	279.50	286.36			
120.0	253.84	255.02	256.19	257.36	258.54	264.46	270.45	276.52	282.68		
125.0	247.14	248.25	249.35	250.46	251.57	257.11	262.66	268.23	273.82	285.13	296.66
130.0	240.73	241.79	242.85	243.91	244.97	250.24	255.49	260.72	265.93	276.35	286.80
135.0	234.45	235.48	236.51	237.53	238.56	243.63	248.66	253.64	258.58	268.36	278.06
140.0	228.23	229.24	230.24	231.24	232.24	237.17	242.03	246.82	251.55	260.85	270.00
145.0	222.04	223.03	224.02	225.00	225.98	230.80	235.53	240.17	244.74	253.68	262.39
150.0	215.89	216.87	217.84	218.81	219.77	224.51	229.14	233.67	238.12	246.76	255.13
155.0	209.79	210.76	211.72	212.68	213.63	218.31	222.87	227.31	231.64	240.05	248.15
160.0	203.75	204.72	205.67	206.63	207.57	212.21	216.70	221.07	225.33	233.54	241.41
165.0	197.80	198.76	199.72	200.67	201.61	206.21	210.66	214.98	219.16	227.22	234.90
170.0	191.95	192.91	193.87	194.82	195.76	200.34	204.76	209.03	213.16	221.08	228.60
175.0	186.22	187.18	188.14	189.09	190.03	194.61	199.01	203.24	207.33	215.14	222.52
180.0	180.61	181.58	182.55	183.50	184.44	189.03	193.41	197.62	201.67	209.38	216.65
185.0	175.14	176.12	177.09	178.05	179.00	183.60	187.97	192.16	196.19	203.83	210.99
190.0	169.81	170.80	171.78	172.75	173.71	178.32	182.71	186.89	190.89	198.46	205.54
195.0	164.61	165.62	166.61	167.59	168.56	173.22	177.61	181.79	185.78	193.30	200.30
200.0	159.55	160.58	161.59	162.58	163.56	168.27	172.68	176.87	180.85	188.33	195.27
205.0	154.62	155.67	156.70	157.71	158.71	163.47	167.93	172.12	176.10	183.55	190.43
210.0	149.80	150.88	151.94	152.98	153.99	158.84	163.33	167.55	171.54	178.96	185.80
215.0	145.09	146.21	147.30	148.36	149.41	154.35	158.89	163.14	167.14	174.55	181.35
220.0	140.48	141.64	142.77	143.87	144.94	149.99	154.61	158.90	162.91	170.33	177.10
225.0	135.94	137.15	138.33	139.47	140.58	145.77	150.47	154.81	158.85	166.28	173.02
230.0	131.46	132.74	133.97	135.16	136.32	141.68	146.47	150.87	154.95	162.39	169.12
235.0	127.03	128.38	129.68	130.93	132.14	137.69	142.61	147.07	151.19	158.67	165.39
240.0	122.60	124.05	125.44	126.76	128.04	133.81	138.86	143.40	147.58	155.10	161.82
245.0	118.18	119.74	121.22	122.64	123.99	130.03	135.23	139.87	144.10	151.68	158.41
250.0	113.73	115.43	117.03	118.54	119.98	126.33	131.71	136.45	140.75	148.40	155.15
255.0	109.26	111.12	112.85	114.48	116.02	122.71	128.28	133.15	137.53	145.25	152.03
260.0	104.81	106.83	108.71	110.46	112.10	119.16	124.96	129.96	134.42	142.23	149.04
265.0	100.50	102.66	104.66	106.52	108.26	115.70	121.72	126.87	131.42	139.34	146.18
270.0	96.50	98.75	100.82	102.76	104.57	112.33	118.58	123.88	128.53	136.56	143.45
275.0	92.97	95.26	97.34	99.30	101.13	109.08	115.53	120.98	125.74	133.89	140.83
280.0	89.78	92.22	94.32	96.24	98.05	106.01	112.60	118.19	123.05	131.32	138.32
285.0	85.83	89.26	91.63	93.59	95.37	103.17	109.81	115.50	120.46	128.86	135.92
290.0	73.39	85.16	88.75	91.10	92.99	100.60	107.17	112.93	117.97	126.50	133.63
295.0	48.14	76.93	84.65	88.23	90.59	98.31	104.73	110.48	115.59	124.23	131.43
300.0	40.25	62.46	77.92	84.19	87.67	96.26	102.49	108.18	113.31	122.05	129.32

Table 6. Thermal conductivity of ethylene. Units: mW/(m·K)--Continued

T \ P	.1	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
300.0	20.56	20.89	21.35	21.88	22.50	23.22	24.08	25.13	26.46	28.23	30.69
310.0	21.85	22.16	22.59	23.09	23.66	24.31	25.08	25.98	27.07	28.41	30.12
320.0	23.18	23.47	23.88	24.34	24.87	25.47	26.16	26.95	27.88	28.98	30.30
330.0	24.54	24.82	25.21	25.64	26.14	26.69	27.32	28.03	28.84	29.77	30.85
340.0	25.94	26.21	26.57	26.98	27.44	27.96	28.53	29.17	29.90	30.71	31.63
350.0	27.37	27.62	27.96	28.35	28.78	29.26	29.79	30.38	31.03	31.75	32.56
360.0	28.81	29.05	29.38	29.74	30.15	30.60	31.09	31.63	32.23	32.88	33.60
370.0	30.27	30.50	30.81	31.15	31.54	31.96	32.42	32.92	33.47	34.07	34.71
380.0	31.74	31.96	32.25	32.58	32.94	33.34	33.77	34.24	34.75	35.30	35.89
390.0	33.22	33.42	33.71	34.02	34.36	34.74	35.15	35.59	36.06	36.57	37.12
400.0	34.70	34.90	35.17	35.47	35.80	36.15	36.54	36.95	37.39	37.87	38.38
410.0	36.19	36.38	36.64	36.93	37.24	37.57	37.94	38.33	38.75	39.19	39.67
420.0	37.69	37.87	38.12	38.39	38.68	39.01	39.35	39.72	40.12	40.53	40.98
430.0	39.19	39.36	39.60	39.86	40.14	40.45	40.77	41.12	41.50	41.89	42.31
440.0	40.69	40.86	41.08	41.33	41.60	41.90	42.21	42.54	42.90	43.27	43.67
450.0	42.20	42.36	42.58	42.82	43.08	43.36	43.65	43.97	44.31	44.66	45.04
460.0	43.72	43.87	44.08	44.31	44.56	44.83	45.11	45.41	45.73	46.07	46.43
470.0	45.25	45.40	45.60	45.82	46.06	46.31	46.59	46.87	47.18	47.50	47.84
480.0	46.79	46.94	47.13	47.34	47.57	47.82	48.08	48.36	48.65	48.95	49.28
490.0	48.36	48.50	48.69	48.89	49.11	49.34	49.59	49.86	50.14	50.43	50.74
500.0	49.95	50.08	50.26	50.46	50.67	50.90	51.14	51.39	51.66	51.94	52.23

T \ P	6.0	7.0	8.0	9.0	10.0	15.0	20.0	30.0	40.0	50.0
300.0	40.25	62.46	77.92	84.19	87.67	96.26	102.49			
310.0	35.35	44.82	58.92	71.00	78.55	92.31	98.56	109.10		
320.0	33.89	39.39	47.46	57.26	66.30	87.49	94.98	105.37		
330.0	33.59	37.40	42.58	49.13	56.38	81.30	91.13	102.03	110.87	
340.0	33.86	36.76	40.47	45.06	50.38	74.52	86.71	98.91	107.81	
350.0	34.45	36.79	39.66	43.11	47.10	68.35	81.97	95.85	105.00	112.69
360.0	35.24	37.21	39.56	42.30	45.43	63.49	77.40	92.79	102.39	110.18
370.0	36.18	37.89	39.88	42.16	44.72	59.99	73.42	89.81	99.94	107.88
380.0	37.22	38.74	40.47	42.42	44.59	57.66	70.22	87.02	97.64	105.77
390.0	38.33	39.70	41.24	42.96	44.85	56.20	67.78	84.54	95.52	103.84
400.0	39.49	40.75	42.14	43.68	45.36	55.38	65.99	82.43	93.60	102.08
410.0	40.70	41.86	43.13	44.53	46.04	55.02	64.75	80.68	91.92	100.50
420.0	41.95	43.02	44.19	45.48	46.86	54.98	63.93	79.27	90.47	99.09
430.0	43.22	44.22	45.31	46.50	47.77	55.20	63.46	78.16	89.23	97.87
440.0	44.52	45.46	46.48	47.58	48.75	55.60	63.25	77.30	88.21	96.81
450.0	45.84	46.72	47.68	48.71	49.80	56.15	63.27	76.67	87.37	95.91
460.0	47.19	48.02	48.92	49.89	50.91	56.82	63.47	76.25	86.71	95.16
470.0	48.56	49.35	50.20	51.11	52.07	57.60	63.83	76.01	86.21	94.56
480.0	49.96	50.71	51.51	52.37	53.28	58.46	64.32	75.93	85.87	94.09
490.0	51.40	52.10	52.86	53.68	54.53	59.42	64.93	76.01	85.67	93.77
500.0	52.86	53.53	54.26	55.03	55.84	60.45	65.66	76.24	85.62	93.57

TABLE 7. Density (ρ), viscosity (η), and thermal conductivity (λ) of saturated liquid ethylene. Units: density in mol/L, viscosity in 10^{-7} Pa·s, thermal conductivity in mW/(m·K)

T,K	ρ	η	λ
105.0	23.297	6601.3	270.0
110.0	23.072	5625.2	263.1
115.0	22.846	4865.4	256.3
120.0	22.617	4262.8	249.5
125.0	22.388	3777.1	242.7
130.0	22.156	3379.4	236.0
135.0	21.922	3049.3	229.4
140.0	21.686	2771.8	222.9
145.0	21.448	2535.6	216.4
150.0	21.206	2332.4	210.1
155.0	20.962	2155.7	203.9
160.0	20.715	2000.7	197.7
165.0	20.463	1863.4	191.8
170.0	20.208	1740.7	185.9
175.0	19.949	1630.4	180.2
180.0	19.685	1530.2	174.6
185.0	19.416	1438.8	169.1
190.0	19.141	1354.7	163.8
195.0	18.860	1270.0	158.5
200.0	18.571	1204.6	153.4
205.0	18.275	1136.8	148.4
210.0	17.971	1073.0	143.5
215.0	17.656	1012.7	138.7
220.0	17.331	955.4	133.9
225.0	16.993	900.6	129.2
230.0	16.641	848.0	124.5
235.0	16.271	797.2	119.9
240.0	15.882	748.0	115.2
245.0	15.468	699.9	110.6
250.0	15.025	652.6	106.0
255.0	14.544	605.7	101.5
260.0	14.012	558.6	97.3
265.0	13.409	510.4	93.6
270.0	12.694	459.7	90.6
275.0	11.780	403.3	88.3

TABLE 8. Viscosity (η) and thermal conductivity (λ) of dilute gaseous ethylene. Units: viscosity 10^{-7} Pa·s, thermal conductivity, mW/(m·K). Reported viscosity values for temperatures greater than 550 K (marked by the asterisk) are extrapolated beyond the range of the data

T,K	η	λ
180.0	63.6	10.0
190.0	66.8	10.5
200.0	70.0	11.1
210.0	73.3	11.7
220.0	76.6	12.4
230.0	79.9	13.1
240.0	83.3	14.0
250.0	86.6	14.9
260.0	90.0	15.8
270.0	93.4	16.9
280.0	96.8	18.0
290.0	100.2	19.2
300.0	103.6	20.5
310.0	107.0	21.8
320.0	110.3	23.1
330.0	113.6	24.5
340.0	116.8	25.9
350.0	120.1	27.3
360.0	123.3	28.7
370.0	126.4	30.2
380.0	129.6	31.7
390.0	132.7	33.2
400.0	135.7	34.6
410.0	138.8	36.1
420.0	141.8	37.6
430.0	144.8	39.1
440.0	147.7	40.6
450.0	150.6	42.2
460.0	153.5	43.7
470.0	156.4	45.2
480.0	159.2	46.8
490.0	162.0	48.3
500.0	164.8	49.9
510.0	167.5	51.5
520.0	170.3	53.2
530.0	173.0	54.9
540.0	175.7	56.6
550.0	178.4*	58.4
560.0	181.0	60.3
570.0	183.7	62.2
580.0	186.3	64.3
590.0	188.9	66.4
600.0	191.5	68.6
610.0	194.1	70.9
620.0	196.6	73.4
630.0	199.1	76.0
640.0	201.7	78.7
650.0	204.2	81.6
660.0	206.7	84.6
670.0	209.1	87.8
680.0	211.6	91.2

4.1. Uncertainty of the Tables

The uncertainty of the tabulated values can be judged from our estimate of accuracy of the input data, and the deviation plots, Figs. 1, 2, and 5–8. We also attempted to evaluate the data using the criteria of Ref. 5 but this was not always possible: lack of experimental details was a principal drawback. In short, our estimate of uncertainty of the tables is somewhat subjective in that it is influenced by our experience of evaluating similar data for fluids which have a better data base. Overall, we judge both the viscosity and thermal conductivity coefficients to have an uncertainty of about $\pm$ 5% increasing to 10% in the dense liquid.

5. Conclusion

As in our previous work, a general empirical equation has been used to represent the viscosity and thermal conductivity coefficients of ethylene from the dilute gas to the dense liquid. Tables of calculated values are presented.

As pointed out in the Introduction, the tables have to be considered somewhat tentative since the data base from which they were constructed could be improved. To repeat the remark made with respect to ethane[1] and propane,[2] it would be helpful if the more recent experimental techniques devised to measure the transport coefficients could be applied to ethylene. It would be especially useful to have reliable transport data below 200 K since most of the available data in this range are more than 40 years old. Additional transport data for pressures greater than 20 MPa would also be useful.

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References

[1]H. J. M. Hanley, K. E. Gubbins, and S. Murad, J. Phys. Chem. Ref. Data **6**, 1167 (1977).
[2]P. M. Holland, H. J.M. Hanley, K. E. Gubbins, and J.M. Haile, J. Phys. Chem. Ref. Data **8**, 559 (1979).
[3]For example, "Thermophysical Properties of Matter," Vols. 3 and 11, edited by Y. S. Touloukian, S. C. Saxena, and P. Hestermans (IFI/Plenum, New York, 1975); "Thermodynamic and Transport Properties of Ethylene and Propylene," Natl. Bur. Stand. (U.S.), Interagency Report NBSIR 75-763, June 1972; T. Makita, Y. Tanaka, and A. Nagashima, Rev. Phys. Chem. Jpn. **44**, 98 (1975).
[4]R. D. McCarty, "An Equation of State for Fluid Ethylene," Natl. Bur. Stand. (U.S.), Technical Note 1045, July 1981.
[5]H. J. M. Hanley, R. D. McCarty, and W. M. Haynes, J. Phys. Chem. Ref. Data **3**, 979 (1974).
[6]D. E. Diller, H. J. M. Hanley, and H.M. Roder, Cryogenics **10**, 286 (1970).
[7]R. T. Jacobsen, Ph.D. dissertation (University of Washington, Pullman, 1972).
[8]J. Kestin, S. T. Ro, and W. A. Wakeham, Trans. Faraday Soc. **67**, 2308 (1971).
[9]A. B. Van Cleave and O. Maass, Can. J. Res., Sect. B **X3**, 140 (1935).
[10]M. Trautz and R. Heberling, Ann. Phys. (Leipzig) **10**, 155 (1931).
[11]M. Trautz and A. Meister, Ann. Phys. (Leipzig) 7, 409 (1930).
[12]M. Trautz and F. W. Stauf, Ann. Phys. (Leipzig) **2**, 737 (1929).
[13]J. Kestin, H. E. Khalifa, and W. A. Wakeham, J. Chem. Phys. **66**, 1132 (1977).
[14]I. F. Golubev, Viscosity of Gases and Gas Mixtures, Israel Program for Scientific Translations, Jerusalem, 1970. Available from the U.S. Department of Commerce.
[15]I. A. Neduzhii and Yu. I. Khmara, Thermophysical Properties of Hydrocarbons and Their Mixtures, edited by I. A. Neduzhii and Yu. I. Khmara, Kiev Technological Institute of Light Industry, Ukr. SSR, 18 (1967).
[16]D. Misic and G. Thodos, AIChE J. **7**, 264 (1961).
[17]P. M. Graven and J. D. Lambert, Proc. R. Soc. London, Ser. A **205**, 439 (1951).
[18]O. Zimmer, Verh. Dtsch. Phys. Ges. **14**, 471 (1912).
[19]D. L. Timrot, M. A. Serednitskaya, and M. S. Bespalov, Dokl. Akad. Nauk SSSR **220**, 799 (1975).
[20]V. E. Lyusternik and A. G. Zhdanov, Teplofiz. Svoistva Veshchestv Mater. **7**, 95 (1973).
[21]E. W. Comings and R. S. Egly, Ind. Eng. Chem. **33**, 1224 (1941).
[22]E. W. Comings, B. J. Mayland, and R. S. Egly, Illinois Univ. Eng. Expt. Sta. Urbana, Bull. No. **354** (1944).
[23]W. A. Felsing and F. Blankenship, Proc. Okla. Acad. Sci. **24**, 90 (1944).
[24]M. G. Gonikberg and L. F. Vereshchagin, Dokl. Akad. Nauk SSSR **55**, 801 (1947).
[25]I. F. Golubev and V. A. Petrov. Tr. GIAP **2**, 5 (1953).
[26]H. Iwasaki and M. Takahashi, Int. Conf. on High Pressure, Proc. 4th (Kyoto, Japan, 1974), J. Osugi, Editor. Rev. Phys. Chem. Jpn., Special Issue, 523 (1975). We did not include this set of data for two reasons: (1) much of the data are close to the critical point and the viscosity in this region is excluded specially from this report, (2) there is a small discrepancy close to the critical between the densities of these authors and those that follow from the MBWR of Ref. 4. The MBWR could well be slightly in error close to the critical point. This is under discussion.
[27]G.I. Galkov and S. F. Gerf, Zh. Tekh. Fiz. **11**, 801 (1941).
[28]S. F. Gerf and G. I. Galkov, Zh. Tekh. Fiz. **10**, 725 (1940).
[29]S. G. Mason and O. Maass, Can. J. Res., Sect. B **18**, 128 (1940).
[30]J. P. Schlumpf, Sc.D. thesis (Universite des Sciences et Techniques du Languedoc, 1973).
[31]N. S. Rudenko, Sow. Phys. **6**, 470 (1934).
[32]N. S. Rudenko, Zh. Eksp. Teor. Fiz. **9**, 1078 (1939).
[33]A. Eucken, Phys. Z. **14**, 324 (1913).
[34]A. Eucken, Forsch. Geb. Ingenieurwes. **11**, 6 (1940).
[35]H. Senftleben and H. Gladisch, Z. Phys. **125**, 653 (1949).
[36]H. Senftleben, Z. Angew. Phys. **5**, 33 (1953).
[37]J. D. Lambert, K. J. Cotton, M. W. Pailthorpe, A. M. Robinson, J. Scrivins, W. R. F. Vale, and R. M. Young, Proc. R. Soc. London, Ser. A **231**, 280 (1955).
[38]A. M. Chaykin and A. M. Markevich, Zh. Fiz. Khim. **32**, no. 1 (1958).
[39]H. Cheung, L. A. Bromley, and C. R. Wilke, AIChE J. **8**, 221 (1962).
[40]H. Senftleben, Z. Angew. Phys. **17**, 86 (1964).
[41]P. Gray and C. Parkinson, J. Chem. Soc. Faraday Trans. I. **70**, 560 (1974).
[42]N. B. Vargaftik and N. A. Vanicheva, J. Eng. Phys. (Engl. Transl.) **27**, 978 (1974).
[43]J. M. Lenoir and E. W. Comings, Chem. Eng. Prog. **47**, 223 (1951).
[44]F. G. Keyes, Trans. ASME **76**, 809 (1954).
[45]I. F. Golubev, I. B. Shpagina, and Yu. V. Mamonov, Tr. Nauchno-Issled. Proektn. Inst. Azotn. Prom. Prod. Org. Sin. No. **8**, 81 (1971).
[46]I. A. Neduzhii, V. A. Kravets, and A. Ya. Kolomiets, Thermophysical Properties of Hydrocarbons and Their Mixtures, edited by I. A. Neduzhii and Yu. I. Khmara, Kiev Technological Institute of Light Industry, Ukr. SSR, 34 (1967).
[47]A. Ya. Kolomiets, Heat Transfer-Sov. Res. **6**, 42 (1974).
[48]A. A. Tarzimanov and V. A. Arslanov, Teplo-Massoperenos **7**, 81 (1972).
[49]A. A. Tarzimanov and V. S. Lozovoi, Teplofiz. Svoistva Gazov, Mater., Vses. Teplofiz. Konf. Svoistvam Veshechestv Vys. Temp., 4th (1971), I. I. Novikov, Editor. Akad. Nauk. SSSR, Moscow **18** (1973).
[50]Ye. Borovik, A. Matveyev, and Ye. Panina, Zh. Tekh. Fiz. **10**, 988 (1940).
[51]Ye. Borovik, Zh. Tekh. Fiz. **17**, 328 (1947).
[52]M. C. Aggarwal and G. S. Springer, J. Chem. Phys. **70**, 3948 (1979).
[53]J. V. Sengers and J. M. H. Levelt Sengers, *Progress in Liquid Physics*, edited by C. A. Croxton (Wiley, New York, 1978), p. 103.
[54]R. S. Basu and J. V. Sengers, in *Proceedings of the 8th Symposium on Thermophysical Properties* (ASME, New York, 1982).
[55]J. V. Sengers and M. Moldover, Phys. Lett. A **66**, 44 (1978).
[56]M. Vincentini-Missoni, J. M. H. Levelt Sengers, and M. S. Green, Phys. Rev. Lett. **22**, 389 (1969).
[57]H. J. M. Hanley, J. V. Sengers, and J. F. Ely, in *Thermal Conductivity*, edited by P. G. Klemens and T.K. Chu (Plenum, New York, 1976), p. 383.

Appendix. Ethylene Equation of State

The equation of state used in the work is that reported by McCarty in Ref. 4. The form of the equation, and its parameters are reproduced in this appendix.[7]

The equation of state is given by the following functional form:

$$\begin{aligned} P = \rho RT &+ \rho^2(N_1T + N_2T^{1/2} + N_3 + N_4/T + N_5/T^2) \\ &+ \rho^3(N_6T + N_7 + N_8/T + N_9/T^2) \\ &+ \rho^4(N_{10}T + N_{11} + N_{12}/T) + \rho^5(N_{13}) \\ &+ \rho^6(N_{14}/T + N_{15}/T^2) + \rho^7(N_{16}/T) \\ &+ \rho^8(N_{17}/T + N_{18}/T^2) + \rho^9(N_{19}/T^2) \\ &+ \rho^3(N_{20}/T^2 + N_{21}/T^3)\exp(-\gamma\rho^2) \\ &+ \rho^5(N_{22}/T^2 + N_{23}/T^4)\exp(-\gamma\rho^2) \\ &+ \rho^7(N_{24}/T^2 + N_{25}/T^3)\exp(-\gamma\rho^2) \\ &+ \rho^9(N_{26}/T^2 + N_{27}/T^4)\exp(-\gamma\rho^2) \\ &+ \rho^{11}(N_{28}/T^2 + N_{29}/T^3)\exp(-\gamma\rho^2) \\ &+ \rho^{13}(N_{30}/T^2 + N_{31}/T^3)\exp(-\gamma\rho^2) \\ &+ \rho^{13}(N_{32}/T^4)\exp(-\gamma\rho^2). \end{aligned}$$

To be consistent with Refs. 4 and 7, P is in atmospheres, ρ is in mol/L, and T is in kelvins. Further, the critical density used in Ref. 4 in $\rho_c = 7.65$ mol/L.

The coefficients are

$$N_1 = -0.2118612747775\text{E}-01$$
$$N_2 = \ \ 0.1768007621548\text{E}+01$$
$$N_3 = -0.3627254482043\text{E}+02$$

$N_4 = 0.3658701144504E+04$
$N_5 = -0.3156459478617E+06$
$N_6 = 0.5733412064872E-03$
$N_7 = -0.7792322551097E+00$
$N_8 = 0.1133600173536E+03$
$N_9 = 0.2678287322174E+06$
$N_{10} = -0.8534048180713E-04$
$N_{11} = 0.1596572678396E+00$
$N_{12} = -0.2695808039744E+02$
$N_{13} = -0.2637338901020E-02$
$N_{14} = -0.4690235708848E-01$
$N_{15} = -0.6173834045119E+02$
$N_{16} = 0.4516392760359E-02$
$N_{17} = -0.7436308185857E-04$
$N_{18} = 0.1616750044124E+00$
$N_{19} = -0.3516497153457E-02$
$N_{20} = -0.1809031120819E+06$
$N_{21} = -0.1781469735983E+08$
$N_{22} = -0.4731890371452E+04$
$N_{23} = 0.3485761929393E+08$
$N_{24} = -0.2529060981155E+02$
$N_{25} = 0.1030652112797E+04$
$N_{26} = -0.1673134333737E+00$
$N_{27} = -0.1687968640472E+04$
$N_{28} = -0.2027253355413E-03$
$N_{29} = 0.6639584275017E-01$
$N_{30} = -0.1536805727439E-05$
$N_{31} = -0.1213732776785E-03$
$N_{32} = 0.4178954787637E-03$
$\gamma = 0.0172$
$R = 0.08205616$