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An Equation of State
for Fluid Ethylene

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An Equation of State for Fluid Ethylene

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AN EQUATION OF STATE FOR FLUID ETHYLENE¹

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A thermodynamic property formulation for ethylene, developed as a part of a joint industry-government project, is presented. The formulation includes an equation of state, vapor pressure equation, and equation for the ideal gas heat capacity. The coefficients were determined by a least squares fit of selected experimental data. Comparisons of property values calculated using the equation of state with measured values are given. The equation of state is not valid in the critical region ($\rho_c \pm 0.3 \rho_c$ for temperatures of $T_c \pm 0.05 T_c$). Errors on the order of 20 percent for derived properties and 10 percent for density may be encountered near the critical point. Tables of the thermodynamic properties of ethylene for the liquid and vapor phases for temperatures from the freezing line to 450 K with pressures to 40 MPa are presented. The equation of state and its derivative and integral functions for calculating thermodynamic properties are included. Estimates of the accuracy of calculated properties are given. A guide for use of computer programs for the calculation of thermodynamic properties of ethylene with listings of subprograms and a sample program to illustrate the use and results of the program are included.

Key words: Computer programs; equation of state; ethylene; thermodynamic properties; tabular values.

1. Introduction

Six years ago a group of Petrochemical companies and the National Bureau of Standards embarked on a joint industry-government project to determine the thermodynamic properties of ethylene. The first four years of the project were devoted to experimental work, which provided data for the development of a

¹ This work was a joint Industry-Government project under the sponsorship of Celanese Chemical Company, Cities Service Oil Company, Continental Oil Company, Gulf Research and Development, Mobil Chemical Company, Monsanto Polymers and Petrochemicals Company, Phillips Chemical Company, Union Carbide Corp. and the National Bureau of Standards.

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mathematical model for the thermodynamic properties of ethylene. The fifth and final year of the project was spent developing the model.

One of two resulting equations of state for ethylene is presented here for the range of liquid and vapor states for temperatures from the triple-point temperature to 450 K, with pressures to 40 MPa. The second equation of state is for the critical region and appears elsewhere (Hastings, et al. [14]). With a few exceptions, the equation of state presented here represents the selected experimental P-p-T data to within the estimated accuracies of these data. Comparisons to various experimental values of other thermodynamic properties indicate some discrepancies between those experimental data and values calculated using the equation of state. These discrepancies, which are discussed in sections 8 and 9, are particularly evident in the critical region, though some irreconcilable discrepancies are found outside of the critical region. The equation of state given here is not valid in the critical region ($\rho_c \pm 0.3 \rho_c$ for temperatures of $T_c \pm 0.05 T_c$).

The equation of state may be used for the calculation of accurate tables of thermodynamic properties of ethylene within the range of its applicability. This equation may also be readily adapted to systems analysis work where iterative solutions are required to solve the equation for known variable pairs other than density and temperature. A table of thermodynamic properties of ethylene for the range of applicability of the formulation is included here.

In determining the equation of state for ethylene, considerable experimentation in the use of various least squares methods and different functional forms was conducted. Also, experimentation in the use of different groupings of the independent data sets used in determining the equation of state led to the selection of several data sets for use in the least squares determination of the final coefficients.

In addition to the equation of state, the ancillary functions required for the calculation of thermodynamic properties are given. These include a vapor pressure equation, an equation for the ideal gas heat capacity, and equations for the density of the saturated liquid and saturated vapor.

A summary of the available data for ethylene is given, and the ranges of these data are tabulated. Comparisons of these measured data to values calculated from the equation of state have been made to establish the accuracy of the equation of state in representing P-p-T values and other thermodynamic properties. These comparisons have been divided into two groups. The first

group includes those data which were used in the fit and the second group consists of all the data sets that were known to the authors, including those used in the fit. The comparisons to data used in the fit are an indication of the success of the model in representing the data selected for the least squares process, while the comparisons to all data provide information about the relative agreement of data sets from different sources. The latter comparisons are included in Appendix A.

The thermodynamic properties reported here have been calculated using the equation of state and derivative relations among the thermodynamic properties. Since the equation of state has been developed to conform to the Maxwell criterion for phase equilibrium, properties of the liquid may be calculated by continuous integration of the equation of state through the two-phase (liquid-vapor) region of the surface. The liquid-vapor coexistence properties included in the tables have been calculated using the vapor pressure equation to establish the saturation temperature for each specified pressure.

No estimate of the accuracy of this formulation for the region near the critical point is presented here. Since analytic equations of state must fail at the critical point in the representation of anomalous behavior of certain properties, the user of this work is advised that this formulation should not be used within about 5 percent of the critical temperature and 30 percent of the critical density. The recent work of Hastings, et al. [14] should be used to calculate thermodynamic properties of ethylene within the near-critical region. The formulation of Hastings, et al. [14] includes a scaled fundamental equation using revised and extended scaling techniques that is accurate in the representation of critical region data to within 5×10^{-4} K in temperature, 5×10^{-5} MPa in pressure, and 0.03 percent in density. The critical point values of P-p-T used here are taken from Hastings, et al. [14].

Much of the experimental data used in the development of the equation of state for ethylene has been measured as a part of the joint industry-government ethylene project under the direction of the National Bureau of Standards, Office of Standard Reference Data. The availability of high quality measurements of the thermodynamic properties of ethylene has provided excellent definition of the surface of state, and has uncovered some problems of scientific interest in the representation of this surface by present modeling techniques. Further studies of the modeling of the surface of state of fluids of engineering interest may

well make use of the data for ethylene in efforts to improve the representation of data near saturation and in the critical region.

2. Experimental Measurements of the Thermodynamic Properties of Ethylene

2.1 Pressure-Density-Temperature Data

The experimental P- ρ -T data sets for ethylene are listed in table 1. The data for the liquid and vapor states of ethylene form a comprehensive network of values to represent the surface. The distribution of these data is shown in figure 1. For clarity, this figure includes only 2331 data points from the total of 2706 points listed in table 1. The data omitted are near the critical point. In instances where there are two or more papers by the same principal author, the symbols used in the data map represent data by that author from more than one reference.

2.2 Coexistence Properties

Recent measurements of the vapor pressure of ethylene are reported in Douslin and Harrison [6], Straty [33], Bigeleisen, et al. [3], Egan and Kemp [8], Hastings and Levelt-Sengers [13], Michels and Wassenaar [26], Tickner and Lossing [39], and Gammon [9]. Measurements of the orthobaric densities of ethylene are reported in Hastings, et al. [14], Golovskii and Tsymarnyi [10], Menes, et al. [24], and Haynes [15].

2.3 Calorimetric Data

Measurements of the isochoric heat capacity of ethylene for eight isochores have been made by Weber [47]. Nominal densities of these isochores are 4.6, 5.9, 6.7, 11.8, 15.6, 17.8, 21.6 and 20.0 mol/dm³. Values of C_v have been derived from velocity of sound measurements by Gammon [9]. Isobaric heat capacity values for ethylene are reported by Vaschenko [42], by Hejmadi and Powers [16], and by Watanabe [45]. The C_v data of Weber [47] and Gammon [9] and the C_p data of Vaschenko [42], Hejmadi and Powers [16], and Watanabe [45] are illustrated in figure 2. Four C_p data points of Watanabe [45] and one C_p data point of Vaschenko [42] are for pressures below the scale of figure 2 and are not included in the figure. Selected values of the C_v data of Weber [47] were included in the data set used for determining the equation of state. However, these data were used in this work primarily to provide an indication of the reliability of values of C_v and C_p calculated using the equation of state and the ideal gas heat capacity equation.

Table 1. Summary of P-ρ-T Data for Ethylene

Source	Number of Data Points	Pressure Range (MPa)	Temperature Range (K)
Douslin and Harrison [6] ³	331 ⁵	1.4 - 39.6	248-448
	296 ⁶	1.3 - 27.6	238-284
	31 ⁷	5. - 24.6	282-448
Golovskii, et al. [11]	114	1.2 - 59.8	106-232
Golovskii, et al. [12]	162	5.7 - 201.1	199-329
Hastings and Levelt-Sengers [14] ³	141	4.7 - 8.4	279-303
Lee [21]	90	0.2 - 81.8	298-348
Levelt-Sengers [22]	91	0.2 - 3.5	220-273
Michels, et al. [27] ⁴	110	1.7 - 27.8	273-423
Michels and Geldermans [25] ⁴	311	1.7 - 308.3	273-423
Prasad [30]	145	0.2 - 5.6	298-423
Saville [31]	90	0.2 - 4.1	244-293
Straty [33]	244	0.6 - 370.5	105-320
Thomas, et al. [37]	123	3.7 - 25.4	244-354
Thomas and Zander [36]	43	0.3 - 3.0	273-323
Thomas, et al. [38]	87	0.3 - 9.9	253-348
Trappeniers, et al. [40]	675	1.6 - 289.8	273-423
Voityuk and Labinov [44]	74	sat.liq. - 6.0	183-273

³ Data taken as a part of this project.

⁴ These data have been superseded by those of Trappeniers, et al. [40] and are not used in this work.

⁵ Data reported on isochores.

⁶ Data reported on isotherms.

⁷ Data for the critical isochore.

Figure 1. Ethylene PVT Data

Figure 2. Ethylene Heat Capacity Data

2.4 Velocity of Sound Measurements

The velocity of sound of ethylene has been measured extensively. The 753 data points of Dregulyas and Stavtzev [7], Gammon [9], Soldatenko and Dregulyas [32], Terres, et al. [35], Mehl [23], and Herget [17] cover the surface of state as shown in figure 3. Five data points of Gammon [9] on the saturated liquid line are for pressures below the scale of figure 3 and are not shown on the figure. These data were not used in the fitting of the coefficients, except as noted below, but were used to provide confirmation of the accuracy of the resulting equation of state for the calculation of velocity of sound for both liquid and vapor states. Table 2 summarizes the recent velocity of sound data for ethylene.

Table 2. Recent Velocity of Sound Measurements for Ethylene

Source	Number of Data Points	Pressure Range (MPa)	Temperature Range (K)
Dregulyas and Stavtzev [7] ⁸	116	0.15 - 59.0	193-282
Gammon [9] ⁸	200 ⁹	0.0002- 7.9	104-298
Soldatenko and Dregulyas [32] ¹⁰	262	0.03 - 9.9	193-473
Terres, et al. [35]	94	0.1 - 11.8	296-448
Mehl [23]	24	0.1 - 1.0	273-373
Herget [17]	57	3.6 - 7.3	282-296

⁸ Data taken as a part of this project.

⁹ Including 28 data points for the saturated liquid.

¹⁰ Including 10 data points for the saturated vapor.

2.5 Second Virial Coefficients

The second virial coefficient for ethylene is given in a number of the references in section 12. Three of the references, Douslin and Harrison [6], Levelt Sengers and Hastings [22], and Waxman [46] contain second virial coefficients from work which was a part of this project. These values, which are considered to be the best values available, are repeated in table 3 for the

Figure 3. Ethylene Velocity of Sound Data

Table 3. The Second Virial Coefficient $B(T)$ for Ethylene in
the Infinite Series $PV/RT = 1 + B(T)/V + \dots$

$10^3 B(T)(\text{dm}^3/\text{mol})$				
T(K)	Douslin and Harrison [6]	Waxman [46]	Levelt Sengers and Hastings [22]	This Work
448.15	- 52.4	- 52.19		
423.15	- 61.6	- 61.34		
398.15	- 72.3	- 72.11		
373.15	- 84.8	- 84.61		
348.15	- 99.7	- 99.61		
323.15	-117.7	-117.69		
303.15	-135.0			
298.15	-139.8	-139.82		
293.15	-144.9			
288.15	-150.3			
283.15	-155.7			
282.35	-156.7			
278.15	-161.6			
273.15	-167.6	-167.67	-162.53	
268.15	-174.1			
263.15	-180.9		-180.58	
258.15	-188.1			
253.15	-195.5		-194.71	
248.15	-203.5			
243.15	-212.0		-211.57	
238.15	-220.9			
235				- 226.5
233.15			-228.78	
230				- 236.6
223.15			-249.17	
220				- 259.1
210				- 286.0
200				- 318.5
190				- 358.4
180				- 407.9
170				- 469.6
160				- 545.8
150				- 638.4
140				- 746.3
130				- 881.4
120				-1104.7
110				-1427.6
100				-1911.9

convenience of the reader. Temperatures in the table are given on the International Practical Temperature Scale of 1968. There is good agreement among the results of the three independent experiments. The values below 235 K were obtained by the authors by means of a simultaneous fit of Douslin and Harrison [6], Waxman [46] and the velocity of sound data by Gammon [9]. These values were not used in the fit of the final equation of state [eq (1)] but were used to determine saturated vapor densities at temperatures below 235 K.

3. Weighting of the Data

Each data point used in the least squares determination of the coefficients of the equation of state was assigned a weighting factor based upon estimates of uncertainties of the variables reported by the experimenter. In most cases these estimated uncertainties were taken from assessments of the overall accuracy of the data sets. Where reliable estimates of uncertainties were not available, estimated accuracies were determined by comparison to preliminary least squares representations of the surface. The weights used in the fitting process were calculated using approximating functions and the error propagation formula. In several instances, the error propagation weights were modified by the assignment of arbitrary multiplicative factors to increase or lessen the effect of a particular data set on the overall representation of the surface.

4. The Determination of the Equation of State

4.1 Analysis of the Functional Form of the Equation of State

Several functional representations were suggested as possible forms for the equation of state for ethylene. Among these are a 32-term modified Benedict-Webb-Rubin (BWR) equation originally proposed in Jacobsen [18], and four other forms which utilize stepwise regression methods to select individual terms from an initial comprehensive function containing a large number (50 to 80) of possible terms. These four forms include an 80-term modified BWR equation, two 50-term modified BWR equations (one using reduced coordinates and the other a dimensional form), and a 51-term fundamental equation which has been used successfully for other fluids (Jacobsen, et al. [19] and Mui, et al. [29]). For the ethylene data set described in this work, no clear preference for one of these forms over the others could be established on the basis of the quality of the fit of the data, and it was decided to use the pressure explicit dimensional

BWR equation proposed in Jacobsen [18] to represent the data for ethylene excluding a wide range of values near the critical point. This equation form is widely used for other fluids and has been shown to exhibit correct thermodynamic behavior for much of the surface of state. The equation form is given as eq (1).¹¹

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

4.2 The Selection of Data for Multiproperty Fitting

This equation of state for ethylene was determined using experimental thermodynamic data including selected P-p-T, C_v , C_p , velocity of sound data, and data to define saturation states to satisfy the Maxwell criterion for phase equilibrium. The P-p-T data selected for use in the least squares fitting process are illustrated in figure 4. The C_v data of Weber [47] used in the least squares fit were 7 points on the 11.8 mol/dm³ isochore, 13 points at

¹¹ The nonlinear coefficient, $\gamma = 0.0172$, in each exponential term was specified prior to the determination of the linear coefficients.

Figure 4. Ethylene PVT Data Used in the Determination of the Equation of State

15.6 mol/dm³ and 4 points at 19.9 mol/dm³. The velocity of sound data used in determining the equation of state data are illustrated in figure 5.

The multiproperty fitting procedures used here suggest the existence of systematic inconsistencies among the various data. The data sets which were not used in determining the final constants are those which seemed to exacerbate the problem of overall consistency. However, the authors were unable to determine the exact nature of the inconsistencies, and no conclusion as to probable or possible systematic errors within any given data set can be inferred from this work. Although the data near the critical point were excluded from the selected set, the critical point of the equation of state was constrained to the values $T_c = 282.3428$ K, $P_c = 5.0403$ MPa, and $\rho_c = 7.6340$ mol/dm³. A later value of the critical temperature given in [14] is 282.3452 K. The equation of state for ethylene reported here, eq (1) with coefficients from table 4, has been compared to selected data sets to illustrate its accuracy. These comparisons are presented in section 8 and 9. Coefficients for the equation of state (1) for ethylene are given in table 4.

5. Liquid-Vapor and Liquid-Solid Coexistence

5.1 Liquid-Vapor Coexistence

The most difficult part of the fluid surface to model mathematically is that defining the liquid-vapor coexistence conditions. Even excluding the critical region, $T = T_c \pm .05 T_c$ and $\rho = \rho_c \pm .3 \rho_c$, where the equation of state is not valid, the rest of the two phase boundary is subject to errors in representation which may be most obvious in the derivative properties at saturation, i.e., C_v , C_p , and velocity of sound.

The procedure used here was to first obtain equations for the vapor pressure, the saturated vapor density, and the saturated liquid density as functions of saturation temperature. These equations, together with the condition of equality of Gibbs free energy for the coexisting liquid and vapor phases, were then used as input data in the least squares fit of the equation of state.

Recent vapor pressure data for ethylene are summarized in table 5. The vapor pressure equation for ethylene has been determined using the data of Gammon [9], Straty [33], Hastings and Levelt Sengers [13], Douslin and Harrison [6], and Bigeleisen, et al. [3]. The equation used in this work is

Table 4. Coefficients for the Equation of State (1) for Ethylene¹²

N ₁	=	-.2146684366683E-02
N ₂	=	.1791433722534E+00
N ₃	=	-.3675315603930E+01
N ₄	=	.3707178934669E+03
N ₅	=	-.3198282566709E+05
N ₆	=	.5809379774732E-04
N ₇	=	-.7895570824899E-01
N ₈	=	.1148620375835E+02
N ₉	=	.2713774629193E+05
N ₁₀	=	-.8647124319107E-05
N ₁₁	=	.1617727266385E-01
N ₁₂	=	-.2731527496271E+01
N ₁₃	=	-.2672283641459E-03
N ₁₄	=	-.4752381331990E-02
N ₁₅	=	-.6255637346217E+01
N ₁₆	=	.4576234964434E-03
N ₁₇	=	-.7534839269320E-05
N ₁₈	=	.1638171982209E-01
N ₁₉	=	-.3563090740740E-03
N ₂₀	=	-.1833000783170E+05
N ₂₁	=	-.1805074209985E+07
N ₂₂	=	-.4794587918874E+03
N ₂₃	=	.3531948274957E+07
N ₂₄	=	-.2562571039155E+01
N ₂₅	=	.1044308253292E+03
N ₂₆	=	-.1695303363659E-01
N ₂₇	=	-.1710334224958E+03
N ₂₈	=	-.2054114462372E-04
N ₂₉	=	.6727558766661E-02
N ₃₀	=	-.1557168403328E-06
N ₃₁	=	-.1229814736077E-04
N ₃₂	=	.4234325938573E-04
γ	=	0.0172
R	=	.00831434

¹² Coefficients are given for temperature in kelvins, pressure in MPa, and density in mol/dm³.

$$\ln P = N_1 + N_2x + N_3x^2 + N_4x^3 + N_5x^4 + N_6x(1-x)^{N_7} \quad (2)$$

where,

$$x = (1 - T_{tp}/T)/(1 - T_{tp}/T_c) \quad .$$

Table 5. Summary of Vapor Pressure Data for Ethylene

Author	Temperature Range Kelvins	No. of Points
1. Bigeleisen, et al. [3]	104-176	31
2. Douslin and Harrison [6]	238-282	18
3. Gammon [9]	104-282	28
4. Michels and Wassenaar [26]	149-281	30
5. Hastings and Sengers [13]	220-282	35
6. Straty [33]	200-282	27
7. Tickner and Lossing [39] ¹³	95-138	24

¹³ This reference also contains vapor pressures for states below the triple point temperature. Values given in the reference are rounded values. Angus [1], page 3, gives 11 experimental values of the vapor pressure supplied by Lossing. These data have been omitted from comparisons in this section because of their apparent lack of agreement with other vapor pressure data for ethylene.

The values of T_{tp} and T_c for use in this equation are $T_{tp} = 103.986$ K and $T_c = 282.3428$ K. The coefficients of this equation for pressure in MPa and temperature in kelvins are given in table 6. Comparisons of values of saturation temperature calculated from the vapor pressure equation at data point pressures with the measured temperatures are given in figure 6. Three values from Gammon [9] for temperatures from 104-113 K exhibit deviations of from -0.8 to -1.8 K and are not included in figure 6. Saturated liquid and vapor density data used in constructing the two phase boundaries as outlined above are summarized in table 7.

Figure 6. Comparisons of PVT Values at Saturation

Table 6. Coefficients for the Vapor Pressure Eq (2) for Ethylene

N_1	=	-9.017286635
N_2	=	8.209579800
N_3	=	4.315424145
N_4	=	-1.692585975
N_5	=	-0.1976495575
N_6	=	3.446501098
N_7	=	1.5

Table 7. Summary of Saturation Density Data Used in This Work

Author	Phase	Temperature Range Kelvins	No. of Points
<hr/>			
Douslin and Harrison [6]	Liquid	238-282	14
	Vapor	238-281	12
Golovskii and Tsymarnyi [10]	Liquid	105-260	30
Hastings and Levelt-Sengers [13]	Liquid	279-282	9
Levelt-Sengers and Hastings [22]	Vapor	220-263	5
Haynes [15]	Liquid	105-200	7
Menes [24]	Liquid	105-175	15

The function for the saturated liquid density is

$$Y = A_1 \ln x + \sum_{i=2}^4 A_i [1 - x^{(i-5)/3}] + \sum_{i=5}^7 A_i [1 - x^{(i-4)/3}] \quad (3)$$

$$\rho_{satl} = \rho_c + e^Y (\rho_{tp1} - \rho_c) ,$$

where $x = (T - T_c)/(T_{tp} - T_c)$ and that for the saturated vapor density is

$$Y = A_1 \ln(x) + \sum_{i=2}^4 A_i [1 - x^{(i-5)/3}] + \sum_{i=5}^{13} A_i [1 - x^{(i-4)/3}] \quad (4)$$

$$\rho_{\text{satv}} = \rho_c + e^Y (\rho_{\text{tpv}} - \rho_c) ,$$

where x is as defined above. The coefficients for these equations used to represent the saturated liquid and vapor densities are given in table 8. These functions for the saturated liquid and saturated vapor densities are also useful to obtain a first approximation to the saturation density when solving the equation of state iteratively for the conditions at phase equilibrium.

Table 8. Coefficients for Approximating Functions for Saturation Densities for Ethylene¹⁴

Coefficients for Saturated Vapor (eq 4)		Coefficients for Saturated Liquid (eq 3)	
ρ_{tpv}	= .142545512709E-03	ρ_{tp1}	= .233429669403E+02
A_1	= -.609621515594E+02	A_1	= -.479047060183E+01
A_2	= .203185312702E-01	A_2	= .151381345283E-01
A_3	= -.925441265813E+00	A_3	= -.403456079445E+00
A_4	= .243630795888E+02	A_4	= .508683920225E+01
A_5	= -.854745622888E+03	A_5	= -.246711997987E+02
A_6	= .123927868183E+04	A_6	= .980030915247E+01
A_7	= -.142710711789E+04	A_7	= -.216846516122E+01
A_8	= .837358670405E+03		
A_9	= .432203696552E+03		
A_{10}	= -.137917541161E+04		
A_{11}	= .126858600124E+04		
A_{12}	= -.571552321713E+03		
A_{13}	= .106012234360E+03		

¹⁴ Coefficients are given for T in kelvins and ρ in mol/dm^3 .

The table of saturation properties in Appendix 3 was calculated by specifying T and then solving the vapor pressure equation, (2), for the saturation pressure. Using the P-T coordinates of a vapor pressure point, the equation of state (1) was then solved for the density of the saturated liquid and vapor using an appropriate iterative procedure. Figure 6 illustrates the agreement between the densities calculated in the above manner and corresponding values from various sources.

An alternative method of calculating the saturation properties is to solve the equation of state for the thermodynamic conditions for coexisting phases, i.e., equal Gibbs free energy for constant P and T. This calculation is accomplished by equating Gibbs free energy of the liquid to the Gibbs free energy of the vapor and the pressure of the liquid equal to the pressure of the vapor at a common temperature. This results in two equations in two unknowns, i.e., density of the vapor and density of the liquid. As a matter of interest this calculation was done for the equation of state reported here and the results are shown in table 9.

5.2 Liquid-Solid Coexistence

The melting line equation used in this work is taken from Straty [33]. This equation is

$$P = 0.00012 + 357.924 (T/T_{tp} - 1.0)^{2.0645} \quad (5)$$

for pressure in MPa and temperature in kelvins where T_{tp} is 103.986 K.

6. The Ideal Gas Heat Capacity Equation

The ideal gas isobaric heat capacity values from Angus, et al. [1] for temperatures from 100 to 500 K have been represented by an equation suggested by Barieau [2].

$$C_p^0/R = N_1/T^3 + N_2/T^2 + N_3/T + N_4 + N_5T + N_6T^2 + N_7T^3 + N_8u^2e^u/(e^u-1)^2, \quad (6)$$

where C_p^0 is the ideal gas heat capacity, T is the temperature in kelvins, and $u = N_9/T$. The coefficients of eq (6) for temperatures in kelvins are given in table 10.

Table 9. Differences Between Saturation Properties Calculated From Equation of State (1) Using the Maxwell Criterion and the Intersection of the Vapor Pressure eq (2) With the Equation of State (1).

Temp. K	ΔP^{15} (MPa)	$\Delta \rho_{\text{vapor}}$ (mol/dm ³)	$\Delta \rho_{\text{liq}}$ (mol/dm ³)	ΔG_{vapor} (J/mol)	ΔG_{liq} (J/mol)
110	-0.03	-0.3	$-5. \times 10^{-5}$	0.1	$1. \times 10^{-6}$
120	-0.008	-0.08	$-7. \times 10^{-8}$	0.02	$1. \times 10^{-6}$
130	-0.002	-0.02	$-9. \times 10^{-9}$	$4. \times 10^{-3}$	$3. \times 10^{-7}$
140	-0.006	-0.06	$-6. \times 10^{-7}$	$1. \times 10^{-2}$	$5. \times 10^{-6}$
150	-0.01	-0.1	$-4. \times 10^{-5}$	$2. \times 10^{-2}$	$2. \times 10^{-5}$
160	-0.02	-0.2	$-5. \times 10^{-5}$	$2. \times 10^{-2}$	$7. \times 10^{-5}$
170	-0.02	-0.2	$-4. \times 10^{-4}$	$4. \times 10^{-2}$	$1. \times 10^{-4}$
180	-0.02	-0.3	$-9. \times 10^{-5}$	$3. \times 10^{-2}$	$2. \times 10^{-4}$
190	-0.02	-0.2	$-2. \times 10^{-4}$	$3. \times 10^{-2}$	$3. \times 10^{-4}$
200	-0.02	-0.2	$-2. \times 10^{-4}$	$1. \times 10^{-2}$	$3. \times 10^{-4}$
210	-0.009	-0.1	$-2. \times 10^{-4}$	$9. \times 10^{-3}$	$2. \times 10^{-4}$
220	-0.003	-0.04	$-1. \times 10^{-4}$	$3. \times 10^{-3}$	$8. \times 10^{-5}$
230	0.001	0.01	$2. \times 10^{-4}$	$-9. \times 10^{-4}$	$-1. \times 10^{-4}$
240	0.004	0.05	$8. \times 10^{-4}$	$-3. \times 10^{-3}$	$-3. \times 10^{-4}$
250	0.005	0.08	$2. \times 10^{-3}$	$-3. \times 10^{-3}$	$-5. \times 10^{-4}$
260	0.004	0.08	$4. \times 10^{-3}$	$-2. \times 10^{-3}$	$-5. \times 10^{-4}$
270	0.002	0.07	$8. \times 10^{-3}$	$-8. \times 10^{-4}$	$-4. \times 10^{-3}$

¹⁵ All property differences are formed by subtracting the property obtained by using the equation of state only from the property obtained by intersecting the vapor pressure equation with the equation of state.

Table 10. Coefficients for the Ideal Gas Heat Capacity
Eq (6) for Ethylene

N_1	=	0.5603615762E+6
N_2	=	-0.2141069802E+5
N_3	=	0.2532008897E+3
N_4	=	0.3554495281E+1
N_5	=	-0.9951927478E-2
N_6	=	0.5108931070E-4
N_7	=	-0.1928667482E-7
N_8	=	-0.2061703241E+2
N_9	=	0.3000000000E+4

Values of the ideal gas heat capacity calculated using this equation have been compared to values calculated using the equation published by Angus, et al. [1]. The agreement of these calculated values is generally within ± 0.01 percent except at temperatures above 460 K where the differences increase to 0.03 percent. A comparison of values of the ideal gas heat capacity calculated using this equation with those of more recent work by Chao and Zwolinski [4], ideal gas heat capacities derived from the low density velocity of sound measurements by Moldover [28] values from Angus [1], and values from the JANAF tables [34] are shown in figure 7. Not shown in the figure are three points of Chao and Zwolinski [4] at 50 K, 319 K, and 340 K which exhibit deviations of -4.1 percent, -0.95 percent, and -1.25 percent respectively.

7. Derived Thermodynamic Properties

Functions for the calculation of entropy, enthalpy, internal energy, the isotherm derivative $(\partial P/\partial p)_T$, the isochore derivative $(\partial P/\partial T)_p$, C_v , C_p , and the velocity of sound have been calculated for the thermodynamic formulation presented here. The basis for these calculations is described in this section.

Figure 7. Comparisons of Ideal Gas Heat Capacity Values

The entropy of any thermodynamic state may be calculated from

$$S(T, \rho) = S_{T_0}^0 + \int_{T_0}^T (C_p^0/T) dT - R \ln(RT\rho/P_0) \\ + \int_0^\rho [R/\rho - (1/\rho^2)(\partial P/\partial T)_\rho]_T d\rho \quad (7)$$

The ideal gas specific heat, C_p^0 , is from eq (6). The reference entropy of the ideal gas at $T_0 = 298.15$ K and $P_0 = 0.101325$ MPa, $S_{T_0}^0 = 219.225$ J/(mol K) is taken from Angus, et al. [1].

The enthalpy of any state may be calculated from

$$H(T, \rho) = H_{T_0}^0 + T \int_0^\rho [(R/\rho) - (1/\rho^2)(\partial P/\partial T)_\rho]_T d\rho \\ + \int_0^\rho [(P/\rho^2) - (RT/\rho)_T] d\rho + (P - \rho RT)/\rho + \int_{T_0}^T C_p^0 dT \quad (8)$$

The reference enthalpy of the ideal gas at $T_0 = 298.15$ K of $H_{T_0}^0 = 29.610$ J/mol was taken from Angus, et al. [1].

The internal energy of a fluid state is calculated from

$$U(T, \rho) = H(T, \rho) - P/\rho \quad (9)$$

The specific heat at constant volume, C_v , of liquid and gas phase points is calculated using the relation

$$C_v(T, \rho) = (C_p^0 - R) - \int_0^\rho [(T/\rho^2)(\partial^2 P/\partial T^2)_\rho]_T d\rho \quad (10)$$

where C_p^0 at temperature, T , is calculated from eq (6).

The specific heat at constant pressure, C_p , is given by

$$C_p(T, \rho) = C_v(T, \rho) + [(T/\rho^2)(\partial P/\partial T)_\rho^2/(\partial P/\partial \rho)_T] \quad (11)$$

The velocity of sound is calculated from the relation,

$$W(T, \rho) = [(C_p/C_v) (\partial P/\partial \rho)_T]^{1/2} \quad (12)$$

The representations for the properties are continuously integrated through the two-phase region to define states in the liquid range. This was made possible by

the fitting procedures employed in the development of the equation of state in which the conditions for two-phase equilibrium were included in the least squares determination of the coefficients for the equation of state. A table of properties of ethylene is included in Appendix B.

8. Comparisons of the Equation of State to P- ρ -T Data

Comparisons of values of density calculated using the equation of state with experimental densities used in determining the coefficients of eq (1) are included in the graphs of figure 8. Calculated density deviations for thirty-nine of the selected data points of Douslin and Harrison [6] and six data points of Hastings, et al. [14] exceeded the scale of figure 8. Thirty-four of these points of Douslin and Harrison and all of the points of Hastings are in the critical region (within ± 30 percent of the critical density and within ± 5 percent of the critical temperature). Comparisons to all P- ρ -T data including those data not used in the determination of the equation of state are given in Appendix A. The critical region is outside the range of this formulation; however to illustrate the actual behavior of the formulation in the critical region, comparisons with critical region data are included in Appendix A.

9. Comparisons of the Equation of State With Related Thermodynamic Data

Although only selected thermodynamic data together with the P- ρ -T data were used in determining the equation of state, comparisons to these data as well as other derived property data are given here to indicate the accuracy of the equation of state in representing these related properties. Figure 9 includes comparisons with the C_v data of Weber [47]¹⁶ and with values from Gammon [9]. Table A-2 includes values of C_v which exhibit deviations larger than the scale of figure 9.

Comparisons to the velocity of sound data used in determining the equation of state are illustrated in figure 10. Five data points of Dregulyas [7] have deviations beyond the scale of figure 10 ranging from -1.1 to -3.8 percent. Thirteen data points of Gammon [9] have absolute deviations from 1.1 to 1.7 percent, and are also excluded from figure 10. Figure 11 is a comparison to the

¹⁶ Data taken as a part of this project.

Figure 8. Deviations of Calculated Values of Density from Selected PVT Data

Figure 8. Deviations of Calculated Values of Density from Selected PVT Data
(Continued)

**Figure 8. Deviations of Calculated Values of Density from Selected PVT Data
(Continued)**

Figure 8. Deviations of Calculated Values of Density from Selected PVT Data
(Continued)

Figure 8. Deviations of Calculated Values of Density from Selected PVT Data
(Continued)

◇ DOUSLIN [6] ISOCHORES

Figure 8. Deviations of Calculated Values of Density from Selected PVT Data
(Continued)

Figure 9. Deviations of Calculated Values of Heat Capacity From Data

Figure 10. Deviations of Calculated Values of Velocity of Sound from Selected Data

Figure 10. Deviations of Calculated Values of Velocity of Sound from Selected Data (Continued)

PERCENT DEVIATION IN VELOCITY OF SOUND

Figure 11. Deviation of Calculated Values of Velocity of Sound from
Selected Data for the Saturated Liquid of Gammon [9]

data of Gammon [9] for the velocity of sound of the saturated liquid used in the fit of the equation of state. Four data points between temperatures of 280 K and 282.15 K were excluded from the fit, and one point near 260 K has a deviation exceeding one percent and is not shown in figure 11. Comparisons to all available single phase velocity of sound data are given in Appendix A. Using saturated vapor states determined by extrapolation of the equation of state to the vapor pressure has resulted in some improvement in the comparison to the saturated liquid velocity of sound values of Gammon over saturation values determined by other methods. The resulting improvements did not significantly alter the P-p-T representation of this formulation from that of preliminary fits of the P-p-T data alone, and the final values of saturation densities are generally within the estimated accuracy of the measured data of Golovskii and Tsymarnyi [10] and Haynes [15]. These comparisons indicate large discrepancies between the data and values of the velocity of sound calculated from this formulation at and near saturation above 230 K in both liquid and vapor states. The values calculated using this formulation in this region must be considered unreliable.

Figure 12 shows comparisons between the experimental C_p data by Hejmadi and Powers [16]¹⁶ by Watanabe [45], and by Vashchenko [43] and corresponding calculated values from eq (1). Data points with deviations beyond the scale of figure 12 are also included in table A-2 in Appendix A.

Table 11 gives a comparison among the heats of vaporization calculated using the eq (1), those of Douslin [6], and the data of Kozlov [20]. Other heat of vaporization data, Douslin [6], Egan and Kemp [8], Clusius and Konnertz [5], and Tully and Edmister [41], are included for comparative purposes.

The data from Kozlov [20] are a result of a cooperative effort between this project and the Data Center of the State Service of Standard Reference Data for Organic Compounds at Kiev in the USSR. This project furnished the laboratory in Kiev with an ultra-pure sample of ethylene; in return, the Kiev laboratory agreed to make heat of vaporization measurements and velocity of sound measurements on that sample and furnish the project with the results prior to their publication. Both the heats of vaporization and velocity of sound data

¹⁶ Data taken as a part of this project.

Figure 12. Comparisons of Calculated Values of C_p with Data

Figure 12. Comparisons of Calculated Values of C_p with Data (Continued)

Table 11. Comparison of Calculated and Experimental Data for the Enthalpy of Vaporization

	$\frac{T}{K}$	$\frac{\Delta H_{data}}{J/mol^{-1}}$	$\frac{\Delta H_{eq (2)}}{J/mol^{-1}}$	$\frac{\Delta H_{data} - \Delta H_{eq (2)}}{J/mol^{-1}}$
Kozlov [20]	150.04	14668	14288	380
	159.87	14223	13918	308
	169.95	13817	13516	301
	179.94	13359	13090	269
	190.12	12933	12622	311
	200.15	12400	12121	279
	219.89	11274	10976	298
	229.89	10515	10286	229
	239.61	9763	9515	248
	273.14	5216	5211	4
	273.49	5153	5134	19
Douslin and Harrison [6] ¹⁷	238.15	9635	9638	- 2.7
	243.15	9202	9203	- 0.2
	248.15	8724	8727	- 2.4
	253.15	8197	8201	- 3.0
	258.15	7610	7615	- 4.3
	263.15	6946	6948	- 1.7
	268.15	6164	6168	- 3.5
	273.15	5194	5209	- 14.7
Clusius and Konnertz [5]	143.4	14327	14529	-202
	169.5	13394	13534	-140
	191.9	12523	12536	- 13
	209.8	11661	11591	70
	236.0	9678	9815	-137
	254.0	7854	8106	-252
Egan and Kemp [8]	169.4	13544	13539	5
Tully and Edmister [41]	244.1	9371	9115	256
	245.1	9041	9022	19
	270.9	5601	5670	- 69

¹⁷ Data were derived by the authors from their PVT measurements.

have been received from the USSR. As shown in table 11, the heats of vaporization from Kozlov [20] do not agree with the present correlation and are believed to be incorrect. These heats of vaporization were not used in the fit of eq (1). The velocity of sound data of Dregulyas and Stavtzev [7] are in good agreement with those of Cammon [9] and proved to be of considerable value in the correlation as they provided information in the compressed liquid region where no other velocity of sound measurements exist. The velocity of sound data of Dregulyas and Stavtzev [7] were used in the fit of eq (1).

10. Estimated Accuracy of the Equation of State

The equation of state presented here may be used to calculate properties of ethylene for liquid and vapor states from the triple point temperature to 450 K with pressures to 40 MPa. Based upon the deviations of calculated values from data values, the accuracy of the equation of state is estimated as ± 0.20 percent in density for most of both liquid and vapor regions of the surface. At the highest temperatures, i.e., above 400 K, the uncertainty is estimated as ± 0.3 percent in density. The equation is not valid near the critical point and should not be used for states within 30 percent of the critical density at temperatures within 5 percent of the critical temperature. The formulation should be considered accurate to within ± 2.5 percent for the calculation of heat capacity values, and within about ± 1 percent for the calculation of velocity of sound except in the critical region, and at (and near) the saturated liquid and saturated vapor states where the deviations may be larger. A possible additional source of error when calculating thermodynamic properties using any equation of state, no matter how accurate that equation of state might be, is the error resulting from errors in the input variables. This error is especially important in the case of custody transfer when the equation of state together with a measured pressure and temperature is used as a means of determining the total mass. Figure 13, reproduced from Thomas, et al. [37], illustrates the resulting errors in density due to errors in the input pressure and temperature. The chart has been constructed for an assumed error in measurement of temperature of 0.5 K and an assumed error in pressure of 0.5 percent. Except for the liquid region where the errors in density are almost entirely the result of the assumed error in temperature, the resulting error in density as shown in figure 13, is divided about equally between the assumed errors in pressure and temperature. The chart may be used for other assumed errors in pressure and temperature by a linear

Figure 13. Accuracy of the Equation of State for Assumed Errors in Temperature and Pressure (0.5 K, 0.5% P) from Thomas et. al [37]

translation; for example, if the assumed errors in pressure and temperature are doubled, the resulting error in density is doubled. Figure 13 is intended as a general guide, and for a more accurate assessment of these errors the equation

$$\Delta \rho = \left(\frac{\partial \rho}{\partial T} \right)_P \Delta T + \left(\frac{\partial \rho}{\partial P} \right)_T \Delta P \quad (13)$$

should be used. The $\left(\frac{\partial \rho}{\partial T} \right)_P$ and $\left(\frac{\partial \rho}{\partial P} \right)_T$ may be obtained from the tables in Appendix 3 by

$$\left(\frac{\partial \rho}{\partial T} \right)_P = - \left(\frac{\partial P}{\partial T} \right)_\rho \left(\frac{\partial \rho}{\partial P} \right)_T^{-1} \quad (14)$$

and

$$\left(\frac{\partial \rho}{\partial P} \right)_T = \left(\frac{\partial P}{\partial \rho} \right)_T^{-1} \quad (15)$$

11. Conclusion

At the beginning of this project, the goal was to provide a mathematical model of the thermodynamic surface of ethylene and new property tables more accurate than those of prior formulations. It was expected that these results would be accurate to within ± 0.1 percent in density and within ± 1 percent in derived properties such as C_v . In addition to the general accuracy statement above, the model was to include the critical region by using a switching function as the critical region is encountered. This would accomplish the merger of the critical region model of Hastings, et al. [14] with this formulation. The merger of the two equations was not accomplished and the reader who wishes to make calculations in the critical region ($\rho_c \pm .3 \rho_c$ for temperature of $T_c \pm .05 T_c$) should use the equation of state in Hastings, et al. [14].

Although a substantial improvement has been made over the equations and tables available six years ago, the accuracy goal has probably not been achieved. Unfortunately the two major sets of P-p-T data used in the development of the model, i.e., Straty [33] and Douslin and Harrison [6], disagree by as much as 0.2 percent in regions common to the two data sets. A good deal of effort, including additional experimental work and alternate methods of data analysis, was expended

in trying to resolve this disagreement without success. At the start of this work, the discrepancy between the two data sets was as large as 0.25 percent. This disagreement was resolved in part by Straty when he verified that some adsorption had taken place in his early experiments. He built a new cell, and repeated the experiment. The data from the second experiment agreed more closely with those of Douslin and Harrison [6], but a 0.2 percent disagreement persists. Impurities do not seem to be a possible cause of the discrepancy as ultra-pure samples were used in both Straty's and Douslin's experiments. Straty repeated some of his experiments with ethylene which had substantial amounts of known impurities, with very little change in the results.

A similar situation exists in the C_v data of Weber [47], but in this case the disagreement is in a single source. There are apparent inconsistencies among the various isochores. As a consequence, only a portion of the data were used in determining the coefficients for the equation of state as outlined in section 4.

In view of the above mentioned discrepancies, and others, it was decided that until these discrepancies are resolved either by experimentation or by additional data analysis, further work on the development of the equation of state is not warranted. Any improvements in the model using the available data would require new methods of correlation or new techniques of data analysis.

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Nomenclature

<u>Symbol</u>	<u>Physical Quantity</u>	<u>Unit Symbol</u>
T	Temperature	K
P	Pressure	MPa
ρ	Density	mol/dm ³
v	specific volume	dm ³ /mol
U	Internal energy	J/mol
G	Gibbs function (Gibbs free energy)	J/mol
H	Enthalpy	J/mol
S	Entropy	J/(mol·K)
C _p	Isobaric heat capacity	J/(mol·K)
C _v	Isochoric heat capacity	J/(mol·K)
W	Velocity of sound	m/s
L	Latent heat	J/mol
B(T)	Second virial coefficient	dm ³ /mol
$(\partial P/\partial \rho)_T$	Isotherm derivative	dm ³ /MPa/mol
$(\partial P/\partial T)_\rho$	Isochore derivative	MPa/K

Superscript

o	Ideal gas property
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Subscripts

o	Reference state property
c	Critical point property
σ	Property at saturation
tp	Triple point property
eqn	Calculated using an equation
data	Experimental value
nbp	Normal boiling point
satv	Saturated vapor
satl	Saturated liquid
tpv	Triple point (vapor)
tpl	Triple point (liquid)

Molecular weight of ethylene, 28.054.

Gas constant, $R = 8.31434 \text{ J/(mol·K)}$.

Nomenclature

<u>Symbol</u>	<u>Fixed Points</u>	<u>Value</u>
T_c	Critical temperature	282.3428 K
P_c	Critical pressure	5.0403 MPa
ρ_c	Critical density	7.6340 mol/dm ³
T_{tp}	Triple point temperature	103.986 K
P_{tp}	Triple point pressure	1.213 x 10 ⁻⁴ MPa
ρ_{tpv}	Triple point density (vapor)	1.42546 x 10 ⁻⁴ mol/dm ³
ρ_{tpl}	Triple point density (liquid)	23.343 mol/dm ³
T_{nbt}	Normal boiling point temperature	169.41 K
P_{nbp}	Normal boiling point pressure	0.101325 MPa
ρ_{nbpv}	Normal boiling density (vapor)	0.07445 mol/dm ³
ρ_{nbpl}	Normal boiling density (liquid)	20.24 mol/dm ³

APPENDIX A. Comparisons to Available Data Sets Including Those
Used in the Determination of the Coefficients of
the Equation of State (1).

Figure A-1. Comparisons to PVT Data

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Figure A-1. Comparisons to PVT Data (Continued)

Table A-1. Data Points With Deviations Exceeding the
Scale of Figure A-1.
(ISOTHERMAL DATA)

Temperature K	Pressure MPa	Density mol/dm ³	Density Deviation Percent	Author
282.35	5.04	8.50	2.32	Douslin [6]
282.35	5.04	7.75	7.44	Douslin [6]
282.35	5.04	7.50	4.94	Douslin [6]
282.35	5.04	7.25	2.29	Douslin [6]
282.40	5.05	7.65	5.72	Douslin [6]
282.40	5.05	7.60	5.45	Douslin [6]
282.45	5.05	8.00	6.61	Douslin [6]
282.45	5.05	7.75	4.96	Douslin [6]
282.45	5.05	7.65	4.57	Douslin [6]
282.45	5.05	7.60	3.94	Douslin [6]
282.45	5.05	7.50	2.99	Douslin [6]
282.55	5.06	7.65	3.01	Douslin [6]
282.55	5.06	7.60	2.51	Douslin [6]
282.65	5.08	8.50	3.59	Douslin [6]
282.65	5.08	8.00	3.87	Douslin [6]
282.65	5.08	7.75	2.80	Douslin [6]
282.65	5.08	7.65	2.30	Douslin [6]
282.65	5.08	7.60	2.08	Douslin [6]
282.65	5.07	6.75	- 2.03	Douslin [6]
282.65	5.07	6.50	- 2.07	Douslin [6]
282.85	5.10	8.00	3.37	Douslin [6]
282.85	5.10	7.75	2.20	Douslin [6]
283.15	5.12	6.75	- 2.02	Douslin [6]
283.35	5.17	8.50	2.99	Douslin [6]
283.35	5.16	8.00	2.57	Douslin [6]
283.35	5.14	6.75	- 2.00	Douslin [6]
283.35	5.14	6.50	- 2.14	Douslin [6]
283.65	5.20	8.10	2.26	Trappeniers [40]
283.65	5.21	8.71	2.71	Trappeniers [40]
284.15	5.27	8.50	2.46	Douslin [6]
323.15	61.52	17.01	2.02	Lee [21]
323.15	39.64	15.55	2.20	Lee [21]
323.15	19.79	12.93	2.33	Lee [21]
323.15	2.43	1.0	4.50	Prasad [30]
348.15	5.64	2.52	2.14	Prasad [30]

Table A-1. (Continued)
(ISOTHERMIC DATA)

Temperature K	Pressure MPa	Density mol/dm ³	Density Deviation Percent	Author
283.15	5.12	6.50	- 2.19	Douslin [6]
282.65	5.07	7.51	3.98	Hastings [14]
282.34	5.04	7.51	9.72	Hastings [14]
283.15	5.13	7.59	2.25	Hastings [14]
282.65	5.07	7.59	4.49	Hastings [14]
282.34	5.04	7.59	10.48	Hastings [14]
282.65	5.08	7.61	3.89	Hastings [14]
282.55	5.06	7.61	4.96	Hastings [14]
282.45	5.05	7.61	7.07	Hastings [14]
282.34	5.04	7.61	9.90	Hastings [14]
283.15	5.13	7.63	2.43	Hastings [14]
282.65	5.07	7.63	4.79	Hastings [14]
282.34	5.04	7.63	11.19	Hastings [14]
282.36	5.04	7.64	7.58	Douslin [6]
282.37	5.04	7.64	6.95	Douslin [6]
282.38	5.05	7.64	6.40	Douslin [6]
282.39	5.05	7.64	6.58	Douslin [6]
282.40	5.05	7.64	5.68	Douslin [6]
282.41	5.05	7.64	5.54	Douslin [6]
282.42	5.05	7.64	4.58	Douslin [6]
282.43	5.05	7.64	4.87	Douslin [6]
282.45	5.05	7.64	3.69	Douslin [6]
282.55	5.06	7.64	2.71	Douslin [6]
282.65	5.08	7.64	2.22	Douslin [6]
283.15	5.13	7.68	2.60	Hastings [14]
282.65	5.08	7.68	5.11	Hastings [14]
282.50	5.06	7.68	7.55	Hastings [14]
282.34	5.04	7.68	11.52	Hastings [14]
283.15	5.14	8.00	2.88	Douslin [6]
283.15	5.14	8.50	3.24	Douslin [6]
282.37	5.05	8.76	3.15	Hastings [14]
282.34	5.04	8.76	3.08	Hastings [14]
282.21	5.03	8.76	2.30	Hastings [14]
282.19	5.02	8.76	2.08	Hastings [14]
283.65	5.21	8.76	2.83	Hastings [14]
282.34	5.04	8.76	3.64	Hastings [14]
282.22	5.03	8.76	3.21	Hastings [14]
282.19	5.02	8.76	2.93	Hastings [14]
282.19	5.02	8.76	2.81	Hastings [14]
282.19	5.02	8.76	2.98	Hastings [14]
282.19	5.02	8.76	2.93	Hastings [14]
282.17	5.02	8.76	2.29	Hastings [14]
283.65	5.22	8.92	2.43	Hastings [14]
282.34	5.04	8.92	2.44	Hastings [14]

Table A-2. Heat Capacity Data With Deviations Exceeding the Scales of Figures 9 and 12.

Temperature K	Pressure MPa	C_V J/(mol K)	C_V Deviations Percent
C_V Data Points of Weber [47] With Deviations Exceeding 5 percent			
297.3	5.9	47.94	6.0
291.3	5.5	51.23	10.0
285.9	5.1	59.07	21.1
289.8	5.8	54.88	10.5
294.8	6.3	50.85	5.3
C_V Data Points of Gammon [9] With Deviations Exceeding 5 percent			
288.2	5.7	52.11	5.0
284.2	5.2	52.79	7.3
284.2	5.2	52.67	10.6
284.2	5.2	58.44	14.0
284.2	5.2	60.89	17.2
284.2	5.2	61.08	17.6
284.2	5.3	59.91	16.3
284.2	5.3	59.54	16.2
284.2	5.3	57.04	13.6
284.2	5.3	53.76	9.9

Table A-2. (Continued)

Temperature K	Pressure MPa	C_p J/(mol K)	C_p Deviations Percent
C_p Data Points of Hejmadi and Powers [16] With Deviations Exceeding 6 percent			
292.0	6.2	479.7	8.3
292.1	6.21	479.9	8.4
299.0	6.21	180.7	- 7.3
300.4	6.21	153.1	-12.0

C_p Data Points of Vaschenko [42] With Deviations Exceeding 6 percent			
168.9	0.5	62.28	- 8.9
249.6	3.1	110.1	17.6
262.7	3.4	106.7	- 6.1
262.7	3.9	101.2	- 6.5
270.3	5.7	117.0	8.0
273.8	4.1	147.3	-21.2
273.8	4.2	143.1	-19.2
273.6	4.5	137.5	- 9.3
273.6	4.7	131.9	- 6.8
273.7	5.2	157.0	20.1
277.7	5.0	148.8	-15.3
277.4	5.0	142.6	-14.5
277.6	5.1	141.7	-14.0
280.4	5.9	184.2	21.1
280.3	5.9	174.7	17.0
281.6	5.2	302.5	10.6
281.4	5.2	233.0	- 7.4
281.3	5.2	249.1	6.2
282.1	5.2	358.2	12.3

Figure A-2. Comparisons to Velocity of Sound Data

Figure A-2. Comparisons to Velocity of Sound Data (Continued)

Figure A-2. Comparisons to Velocity of Sound Data (Continued)

Table A-3. Velocity of Sound Data With Deviations Exceeding the
Scale of Figure A-2.

Temperature K	Pressure MPa	Velocity of	Velocity of Sound	
		Sound m/s	Deviation Percent	Author
280.15	4.80	208.1	- 3.60	Gammon [9]
280.15	4.82	252.5	- 5.38	Gammon [9]
281.15	4.91	224.9	- 9.40	Gammon [9]
281.15	4.99	261.2	- 3.13	Gammon [9]
281.15	4.88	210.4	- 3.01	Gammon [9]
281.15	4.91	201.6	- 6.06	Gammon [9]
281.65	4.95	201.9	- 5.92	Gammon [9]
281.65	4.96	195.6	- 8.71	Gammon [9]
281.65	4.99	231.0	- 7.12	Gammon [9]
282.22	5.02	200.7	- 5.81	Dregulyas [7]
282.22	5.03	185.1	-13.96	Dregulyas [7]
282.22	5.03	182.2	-15.75	Dregulyas [7]
282.22	5.04	196.5	-16.94	Dregulyas [7]
282.22	5.06	219.8	-10.28	Dregulyas [7]
282.22	5.07	226.1	- 9.23	Dregulyas [7]
282.22	5.14	253.3	- 4.67	Dregulyas [7]
282.35	5.04	163.5	-29.12	Gammon [9]
282.35	5.04	172.3	-22.48	Gammon [9]
282.35	5.04	175.0	-20.77	Gammon [9]
282.35	5.01	205.5	- 4.63	Gammon [9]
282.35	5.10	238.2	- 4.95	Gammon [9]
282.35	5.04	185.5	-19.85	Gammon [9]
282.35	5.04	170.0	-24.24	Gammon [9]
282.35	5.06	210.1	-10.98	Gammon [9]
282.35	5.03	194.1	- 9.53	Gammon [9]
282.85	5.13	202.8	-16.35	Herget [17]
282.85	5.14	193.0	-24.45	Herget [17]
282.85	5.17	160.0	-54.64	Herget [17]
282.85	5.17	162.0	-54.18	Herget [17]
282.85	5.17	165.0	-51.38	Herget [17]
282.85	5.24	225.0	-17.85	Herget [17]
282.85	5.37	263.0	-10.11	Herget [17]
282.85	5.41	280.8	- 5.71	Herget [17]
282.85	5.47	290.0	- 5.22	Herget [17]
282.85	5.53	298.6	- 5.00	Herget [17]
282.85	5.60	309.0	- 4.33	Herget [17]
282.85	5.77	318.0	- 7.18	Herget [17]
283.32	5.16	205.6	- 7.09	Soldatenko [32]
283.32	5.20	189.4	-25.44	Soldatenko [32]
283.32	5.21	188.5	-28.14	Soldatenko [32]
283.32	5.23	203.3	-21.85	Soldatenko [32]
283.32	5.26	211.8	-20.16	Soldatenko [32]
283.32	5.29	228.1	-14.53	Soldatenko [32]
283.32	5.29	231.5	-12.94	Soldatenko [32]
283.32	5.34	241.1	-12.62	Soldatenko [32]
283.32	5.45	271.2	- 7.45	Soldatenko [32]
283.32	5.49	283.7	- 4.86	Soldatenko [32]
283.32	5.50	282.2	- 5.94	Soldatenko [32]
283.32	9.94	517.5	- 6.00	Soldatenko [32]

Table A-3. (Continued)

Temperature K	Pressure MPa	Velocity of	Velocity of Sound	Author
		Sound m/s	Deviation Percent	
284.15	5.25	196.0	-10.74	Gammon [9]
284.15	5.32	228.8	- 4.59	Gammon [9]
284.15	5.24	196.3	- 9.66	Gammon [9]
284.15	5.28	211.7	- 7.73	Gammon [9]
284.15	5.22	200.2	- 7.42	Gammon [9]
284.15	5.26	200.9	-10.04	Gammon [9]
284.15	5.20	205.8	- 4.94	Gammon [9]
291.85	6.23	234.1	- 3.13	Herget [17]
291.85	6.30	240.4	- 3.28	Herget [17]
291.85	6.37	246.5	- 3.01	Herget [17]
291.85	6.87	300.3	- 5.49	Herget [17]
308.67	9.05	326.0	4.10	Soldatenko [32]
448.15	4.90	332.9	-14.55	Terres [35]

APPENDIX B

Thermodynamic Properties of Fluid Ethylene

Table B-1. Thermodynamic Properties of Saturated Ethylene

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of sound m/s
103.986	.00012	23.389 .000140	46.008 .864	2.908 .000	6614.68 21685.64	6614.68 22550.01	84.4 237.7	39.48 24.99	74.41 33.31	1759. 203.
104.	.00012	23.389 .000141	46.027 .864	2.907 .000	6615.72 21685.99	6615.72 22550.48	84.4 237.7	39.49 24.99	74.39 33.31	1759. 203.
105.	.00014	23.327 .000166	47.235 .873	2.842 .000	6689.42 21710.87	6689.43 22583.64	85.1 236.5	40.07 24.99	73.08 33.32	1752. 204.
106.	.00017	23.268 .000195	48.189 .881	2.783 .000	6761.97 21735.74	6761.98 22616.78	85.8 235.4	40.60 25.00	72.07 33.33	1746. 205.
107.	.00020	23.211 .000229	48.934 .889	2.728 .000	6833.64 21760.59	6833.65 22649.91	86.5 234.3	41.08 25.00	71.29 33.34	1740. 206.
108.	.00024	23.156 .000267	49.506 .897	2.678 .000	6904.61 21785.44	6904.62 22683.03	87.1 233.2	41.50 25.01	70.67 33.34	1734. 206.
109.	.00028	23.103 .000311	49.933 .905	2.631 .000	6975.02 21810.27	6975.03 22716.12	87.8 232.2	41.86 25.02	70.17 33.35	1727. 207.
110.	.00033	23.051 .000361	50.237 .914	2.586 .000	7044.97 21835.09	7044.98 22749.20	88.4 231.2	42.18 25.02	69.75 33.36	1721. 208.
111.	.00039	23.000 .000418	50.436 .922	2.545 .000	7114.54 21859.90	7114.55 22782.25	89.0 230.2	42.46 25.03	69.40 33.37	1714. 209.
112.	.00045	22.950 .000482	50.545 .930	2.506 .000	7183.79 21884.69	7183.81 22815.29	89.7 229.2	42.69 25.04	69.11 33.38	1708. 210.
113.	.00052	22.901 .000555	50.576 .938	2.469 .000	7252.77 21909.46	7252.79 22848.29	90.3 228.3	42.89 25.04	68.85 33.39	1701. 211.
114.	.00060	22.852 .000636	50.538 .946	2.434 .000	7321.51 21934.21	7321.53 22881.27	90.9 227.4	43.05 25.05	68.63 33.41	1695. 212.
115.	.00070	22.805 .000728	50.442 .954	2.401 .000	7390.04 21958.94	7390.07 22914.22	91.5 226.5	43.17 25.06	68.44 33.42	1688. 213.
116.	.00080	22.757 .000830	50.294 .963	2.369 .000	7458.39 21983.65	7458.42 22947.13	92.1 225.6	43.27 25.07	68.26 33.43	1682. 214.
117.	.00092	22.710 .000945	50.100 .971	2.339 .000	7526.57 22008.33	7526.61 22980.01	92.7 224.7	43.34 25.08	68.11 33.45	1675. 215.
118.	.00105	22.664 .001072	49.867 .979	2.310 .000	7594.60 22032.99	7594.65 23012.86	93.2 223.9	43.38 25.09	67.96 33.47	1669. 216.
119.	.00120	22.618 .001213	49.599 .987	2.282 .000	7662.50 22057.62	7662.55 23045.67	93.8 223.1	43.41 25.10	67.83 33.48	1662. 217.
120.	.00136	22.572 .001370	49.299 .995	2.256 .000	7730.27 22082.23	7730.33 23078.44	94.4 222.3	43.41 25.11	67.71 33.50	1656. 217.
121.	.00155	22.526 .001543	48.973 1.003	2.230 .000	7797.93 22106.80	7797.99 23111.16	94.9 221.5	43.39 25.13	67.61 33.52	1649. 218.
122.	.00176	22.481 .001735	48.522 1.011	2.205 .000	7865.48 22131.34	7865.56 23143.84	95.5 220.7	43.36 25.14	67.50 33.54	1643. 219.
123.	.00199	22.435 .001946	48.250 1.019	2.181 .000	7932.93 22155.85	7933.02 23176.47	96.0 220.0	43.32 25.16	67.41 33.57	1636. 220.

Table B-1. (Continued)

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of sound m/s
124.	.00224	22.390 .002177	47.860 1.026	2.158 .000	8000.30 22180.33	8000.40 23209.04	96.6 219.2	43.26 25.17	67.32 33.59	1629. 221.
125.	.00252	22.345 .002431	47.453 1.034	2.136 .000	8067.58 22204.76	8067.69 23241.57	97.1 218.5	43.19 25.19	67.25 33.61	1623. 222.
126.	.00283	22.300 .002710	47.031 1.042	2.114 .000	8134.78 22229.16	8134.91 23274.04	97.7 217.8	43.10 25.20	67.17 33.64	1616. 223.
127.	.00317	22.255 .003014	46.597 1.050	2.092 .000	8201.92 22253.52	8202.06 23306.45	98.2 217.1	43.01 25.22	67.11 33.67	1610. 224.
128.	.00355	22.210 .003345	46.152 1.058	2.072 .000	8268.99 22277.84	8269.15 23338.80	98.7 216.5	42.92 25.24	67.04 33.70	1603. 224.
129.	.00396	22.166 .003706	45.698 1.065	2.051 .000	8336.00 22302.12	8336.18 23371.09	99.2 215.8	42.81 25.26	66.99 33.73	1596. 225.
130.	.00441	22.121 .004099	45.235 1.073	2.031 .000	8402.95 22326.35	8403.15 23403.30	99.8 215.1	42.70 25.28	66.94 33.77	1590. 226.
131.	.00491	22.076 .004525	44.765 1.081	2.012 .000	8469.86 22350.53	8470.09 23435.45	100.3 214.5	42.59 25.31	66.89 33.80	1583. 227.
132.	.00545	22.031 .004986	44.289 1.088	1.993 .000	8536.73 22374.67	8536.98 23467.53	100.8 213.9	42.47 25.33	66.85 33.84	1576. 228.
133.	.00604	21.986 .005485	43.808 1.096	1.974 .000	8603.56 22398.75	8603.83 23499.53	101.3 213.3	42.34 25.36	66.82 33.88	1570. 228.
134.	.00668	21.941 .006025	43.324 1.103	1.956 .000	8670.35 22422.78	8670.66 23531.45	101.8 212.7	42.22 25.38	66.79 33.92	1563. 229.
135.	.00738	21.896 .006606	42.835 1.111	1.937 .000	8737.12 22446.76	8737.46 23563.29	102.3 212.1	42.09 25.41	66.76 33.96	1556. 230.
136.	.00813	21.850 .007232	42.345 1.118	1.920 .000	8803.86 22470.68	8804.24 23595.05	102.8 211.5	41.96 25.44	66.74 34.01	1550. 231.
137.	.00895	21.805 .007905	41.852 1.125	1.902 .000	8870.59 22494.55	8871.00 23626.72	103.3 211.0	41.83 25.47	66.73 34.05	1543. 232.
138.	.00983	21.759 .008628	41.359 1.132	1.884 .000	8937.30 22518.36	8937.75 23658.30	103.8 210.4	41.69 25.50	66.72 34.10	1536. 232.
139.	.01079	21.714 .009403	40.865 1.140	1.867 .000	9004.00 22542.10	9004.49 23689.78	104.2 209.9	41.56 25.53	66.71 34.15	1529. 233.
140.	.01182	21.668 .010233	40.370 1.147	1.850 .000	9070.69 22565.78	9071.23 23721.17	104.7 209.4	41.43 25.56	66.71 34.21	1522. 234.
141.	.01293	21.622 .011120	39.877 1.154	1.833 .000	9137.38 22589.40	9137.98 23752.47	105.2 208.8	41.29 25.60	66.71 34.26	1515. 235.
142.	.01413	21.576 .012069	39.383 1.161	1.816 .000	9204.07 22612.95	9204.73 23783.66	105.7 208.3	41.16 25.63	66.71 34.32	1508. 235.
143.	.01541	21.530 .013080	38.892 1.168	1.800 .000	9270.77 22636.44	9271.48 23814.74	106.1 207.8	41.03 25.67	66.72 34.38	1501. 236.
144.	.01679	21.484 .014159	38.401 1.174	1.783 .000	9337.47 22659.85	9338.25 23845.72	106.6 207.3	40.90 25.71	66.73 34.44	1494. 237.
145.	.01827	21.437 .015306	37.913 1.181	1.767 .000	9404.19 22683.19	9405.04 23876.58	107.1 206.9	40.77 25.75	66.75 34.51	1487. 238.

Table B-1. (Continued)

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p	Velocity of sound m/s
146.	.01985	21.391 .016527	37.427 1.188	1.751 .000	9470.92 22706.46	9471.85 23907.33	107.5 206.4	40.64 25.79	66.77 34.58	1480. 238.
147.	.02154	21.344 .017823	36.944 1.194	1.734 .000	9537.67 22729.65	9538.68 23937.96	108.0 205.9	40.51 25.83	66.79 34.64	1473. 239.
148.	.02334	21.297 .019198	36.463 1.201	1.718 .000	9604.45 22752.77	9605.54 23968.48	108.4 205.5	40.39 25.87	66.82 34.72	1466. 240.
149.	.02526	21.250 .020656	35.985 1.207	1.703 .000	9671.24 22775.81	9672.43 23998.87	108.9 205.0	40.26 25.92	66.84 34.79	1459. 240.
150.	.02731	21.202 .022200	35.511 1.214	1.687 .000	9738.07 22798.77	9739.36 24029.13	109.3 204.6	40.14 25.97	66.88 34.87	1452. 241.
151.	.02950	21.155 .023833	35.040 1.220	1.671 .000	9804.92 22821.64	9806.32 24059.26	109.8 204.2	40.02 26.01	66.91 34.95	1445. 242.
152.	.03182	21.107 .025558	34.572 1.226	1.655 .000	9871.81 22844.44	9873.32 24089.26	110.2 203.7	39.91 26.06	66.95 35.03	1438. 242.
153.	.03428	21.059 .027380	34.108 1.232	1.640 .000	9938.73 22867.14	9940.36 24119.13	110.6 203.3	39.79 26.11	66.99 35.11	1431. 243.
154.	.03689	21.011 .029302	33.649 1.238	1.624 .000	10005.69 22889.76	10007.45 24148.85	111.1 202.9	39.68 26.16	67.03 35.20	1423. 244.
155.	.03967	20.963 .031328	33.193 1.243	1.609 .000	10072.69 22912.29	10074.58 24178.44	111.5 202.5	39.56 26.22	67.07 35.29	1416. 244.
156.	.04260	20.914 .033461	32.741 1.249	1.594 .000	10139.73 22934.73	10141.77 24207.87	111.9 202.1	39.46 26.27	67.12 35.38	1409. 245.
157.	.04571	20.866 .035705	32.293 1.255	1.578 .000	10206.81 22957.08	10209.00 24237.16	112.4 201.7	39.35 26.33	67.17 35.48	1402. 245.
158.	.04899	20.817 .038065	31.849 1.260	1.563 .000	10273.94 22979.34	10276.30 24266.30	112.8 201.4	39.24 26.38	67.22 35.57	1394. 246.
159.	.05246	20.768 .040544	31.410 1.265	1.548 .000	10341.12 23001.49	10343.64 24295.28	113.2 201.0	39.14 26.44	67.27 35.67	1387. 247.
160.	.05611	20.718 .043146	30.975 1.271	1.533 .000	10408.34 23023.55	10411.05 24324.11	113.6 200.6	39.04 26.50	67.32 35.78	1380. 247.
161.	.05997	20.669 .045876	30.545 1.276	1.518 .000	10475.61 23045.51	10478.52 24352.77	114.1 200.3	38.95 26.56	67.38 35.88	1372. 248.
162.	.06404	20.619 .048737	30.118 1.281	1.503 .000	10542.94 23067.37	10546.05 24381.27	114.5 199.9	38.85 26.62	67.44 35.99	1365. 248.
163.	.06831	20.569 .051733	29.697 1.285	1.488 .000	10610.32 23089.12	10613.64 24409.60	114.9 199.5	38.76 26.69	67.50 36.10	1358. 249.
164.	.07281	20.519 .054870	29.279 1.290	1.474 .000	10677.75 23110.77	10681.30 24437.76	115.3 199.2	38.67 26.75	67.56 36.22	1350. 250.
165.	.07754	20.469 .058150	28.866 1.295	1.459 .001	10745.24 23132.32	10749.03 24465.75	115.7 198.9	38.58 26.82	67.62 36.33	1343. 250.
166.	.08250	20.419 .061579	28.457 1.299	1.444 .001	10812.79 23153.75	10816.83 24493.56	116.1 198.5	38.49 26.89	67.69 36.46	1336. 251.
167.	.08772	20.368 .065162	28.053 1.303	1.430 .001	10880.39 23175.07	10884.70 24521.18	116.5 198.2	38.41 26.95	67.75 36.58	1328. 251.

Table B-1. (Continued)

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of sound m/s
168.	.09318	20.317 .068902	27.653 1.308	1.416 .001	10948.03 23196.28	10952.64 24548.63	116.9 197.9	38.33 27.02	67.82 36.70	1321. 252.
169.	.09890	20.266 .072804	27.257 1.312	1.401 .001	11015.78 23217.38	11020.66 24575.88	117.3 197.6	38.25 27.10	67.89 36.83	1313. 252.
170.	.10490	20.215 .076872	26.865 1.315	1.387 .001	11083.56 23238.35	11088.75 24602.95	117.7 197.2	38.18 27.17	67.96 36.97	1306. 253.
171.	.11117	20.163 .081112	26.478 1.319	1.373 .001	11151.41 23259.21	11156.93 24629.81	118.1 196.9	38.10 27.24	68.03 37.10	1298. 253.
172.	.11773	20.111 .085529	26.095 1.323	1.359 .001	11219.33 23279.95	11225.18 24656.48	118.5 196.6	38.03 27.32	68.11 37.24	1291. 254.
173.	.12459	20.059 .090126	25.716 1.326	1.344 .001	11287.30 23300.57	11293.51 24682.95	118.9 196.3	37.96 27.39	68.19 37.39	1283. 254.
174.	.13175	20.007 .094910	25.341 1.329	1.331 .001	11355.35 23321.06	11361.93 24709.22	119.3 196.0	37.90 27.47	68.26 37.53	1276. 254.
175.	.13922	19.955 .099884	24.969 1.332	1.317 .001	11423.46 23341.42	11430.44 24735.27	119.7 195.8	37.83 27.55	68.34 37.68	1268. 255.
176.	.14702	19.903 .10505	24.602 1.335	1.303 .001	11491.64 23361.66	11499.03 24761.11	120.1 195.5	37.77 27.63	68.42 37.83	1260. 255.
177.	.15515	19.850 .11043	24.239 1.338	1.289 .001	11559.90 23381.76	11567.71 24786.74	120.5 195.2	37.71 27.71	68.51 37.99	1253. 256.
178.	.16361	19.797 .11600	23.879 1.340	1.275 .001	11628.22 23401.73	11636.48 24812.14	120.9 194.9	37.65 27.80	68.59 38.15	1245. 256.
179.	.17243	19.744 .12179	23.523 1.343	1.262 .001	11696.62 23421.56	11705.35 24837.32	121.2 194.6	37.60 27.88	68.68 38.31	1238. 256.
180.	.18160	19.690 .12780	23.171 1.345	1.248 .001	11765.09 23441.26	11774.31 24862.28	121.6 194.4	37.54 27.97	68.77 38.48	1230. 257.
181.	.19115	19.637 .13403	22.822 1.347	1.235 .001	11833.64 23460.81	11843.37 24887.00	122.0 194.1	37.49 28.05	68.86 38.65	1222. 257.
182.	.20107	19.583 .14048	22.476 1.349	1.222 .001	11902.26 23480.22	11912.53 24911.48	122.4 193.8	37.44 28.14	68.95 38.83	1215. 258.
183.	.21137	19.529 .14717	22.134 1.350	1.208 .001	11970.97 23499.49	11981.79 24935.73	122.8 193.6	37.40 28.23	69.05 39.00	1207. 258.
184.	.22208	19.475 .15410	21.795 1.352	1.195 .001	12039.75 23518.60	12051.15 24959.73	123.1 193.3	37.35 28.32	69.15 39.19	1199. 258.
185.	.23319	19.420 .16127	21.460 1.353	1.182 .001	12108.62 23537.57	12120.63 24983.49	123.5 193.1	37.31 28.41	69.25 39.37	1192. 259.
186.	.24471	19.366 .16870	21.127 1.354	1.169 .002	12177.57 23556.38	12190.21 25006.99	123.9 192.8	37.27 28.51	69.35 39.57	1184. 259.
187.	.25667	19.311 .17638	20.798 1.355	1.156 .002	12246.61 23575.03	12259.90 25030.23	124.3 192.6	37.23 28.60	69.46 39.76	1176. 259.
188.	.26905	19.256 .18432	20.472 1.355	1.143 .002	12315.74 23593.53	12329.71 25053.22	124.6 192.3	37.19 28.70	69.57 39.96	1168. 259.
189.	.28189	19.200 .19253	20.148 1.356	1.131 .002	12384.95 23611.86	12399.64 25075.93	125.0 192.1	37.16 28.79	69.68 40.17	1161. 260.

Table B-1. (Continued)

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of sound m/s
190.	.29517	19.145 .20102	19.828 1.356	1.118 .002	12454.27 23630.02	12469.68 25098.38	125.4 191.8	37.13 28.89	69.80 40.38	1153. 260.
191.	.30893	19.089 .20979	19.510 1.356	1.105 .002	12523.67 23648.02	12539.86 25120.56	125.7 191.6	37.09 28.99	69.92 40.59	1145. 260.
192.	.32315	19.033 .21885	19.195 1.356	1.093 .002	12593.18 23665.85	12610.15 25142.45	126.1 191.4	37.07 29.09	70.04 40.81	1137. 260.
193.	.33787	18.976 .22820	18.882 1.355	1.080 .002	12662.78 23683.50	12680.59 25164.06	126.4 191.1	37.04 29.19	70.17 41.03	1123. 261.
194.	.35308	18.920 .23786	18.572 1.355	1.068 .002	12732.49 23700.98	12751.15 25185.38	126.8 190.9	37.01 29.30	70.30 41.26	1121. 261.
195.	.36879	18.863 .24782	18.265 1.354	1.056 .002	12802.30 23718.27	12821.86 25206.40	127.2 190.7	36.99 29.40	70.43 41.50	1113. 261.
196.	.38502	18.806 .25810	17.960 1.353	1.044 .002	12872.23 23735.37	12892.70 25227.13	127.5 190.5	36.97 29.51	70.57 41.74	1105. 261.
197.	.40178	18.749 .26870	17.658 1.351	1.031 .002	12942.26 23752.29	12963.69 25247.55	127.9 190.3	36.95 29.61	70.72 41.98	1098. 261.
198.	.41907	18.691 .27964	17.357 1.350	1.019 .003	13012.42 23769.02	13034.84 25267.66	128.2 190.0	36.93 29.72	70.86 42.23	1090. 261.
199.	.43691	18.633 .29091	17.059 1.348	1.007 .003	13082.69 23785.55	13106.14 25287.45	128.6 189.8	36.92 29.83	71.02 42.49	1082. 262.
200.	.45531	18.575 .30252	16.764 1.346	.996 .003	13153.08 23801.88	13177.59 25306.92	128.9 189.6	36.90 29.94	71.18 42.75	1074. 262.
201.	.47428	18.517 .31449	16.470 1.344	.984 .003	13223.60 23818.00	13249.21 25326.07	129.3 189.4	36.89 30.06	71.34 43.02	1066. 262.
202.	.49382	18.458 .32683	16.179 1.341	.972 .003	13294.25 23833.92	13321.01 25344.88	129.6 189.2	36.88 30.17	71.51 43.30	1057. 262.
203.	.51395	18.399 .33953	15.890 1.338	.960 .003	13365.04 23849.62	13392.97 25363.35	130.0 189.0	36.87 30.28	71.68 43.58	1049. 262.
204.	.53469	18.340 .35261	15.602 1.335	.949 .003	13435.96 23865.11	13465.11 25381.47	130.3 188.8	36.87 30.40	71.86 43.87	1041. 262.
205.	.55603	18.280 .36608	15.317 1.332	.937 .003	13507.03 23880.37	13537.44 25399.24	130.7 188.6	36.86 30.52	72.05 44.17	1033. 262.
206.	.57800	18.220 .37995	15.034 1.328	.926 .004	13578.24 23895.41	13609.96 25416.65	131.0 188.4	36.86 30.64	72.24 44.47	1025. 262.
207.	.60059	18.160 .39422	14.752 1.325	.915 .004	13649.61 23910.21	13682.68 25433.70	131.4 188.2	36.86 30.76	72.45 44.79	1017. 262.
208.	.62383	18.099 .40891	14.473 1.321	.903 .004	13721.13 23924.78	13755.60 25450.37	131.7 188.0	36.86 30.88	72.65 45.11	1008. 262.
209.	.64772	18.038 .42403	14.196 1.316	.892 .004	13792.81 23939.10	13828.72 25466.66	132.1 187.8	36.86 31.01	72.87 45.43	1000. 262.
210.	.67228	17.977 .43958	13.920 1.312	.881 .004	13864.67 23953.18	13902.06 25482.56	132.4 187.6	36.86 31.13	73.09 45.77	992. 262.
211.	.69751	17.915 .45557	13.646 1.307	.870 .004	13936.69 23967.00	13975.62 25498.06	132.8 187.4	36.87 31.26	73.32 46.12	984. 262.

Table B-1. (Continued)

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of sound m/s
212.	.72343	17.853 .47203	13.374 1.302	.859 .005	14008.89 23980.57	14049.41 25513.16	133.1 187.2	36.88 31.39	73.56 46.47	975. 262.
213.	.75004	17.791 .48895	13.104 1.296	.848 .005	14081.28 23993.87	14123.44 25527.85	133.4 187.0	36.89 31.52	73.80 46.84	967. 262.
214.	.77736	17.728 .50635	12.836 1.291	.837 .005	14153.86 24006.99	14197.71 25542.11	133.8 186.8	36.90 31.65	74.06 47.22	958. 262.
215.	.80540	17.665 .52425	12.569 1.285	.826 .005	14226.63 24019.64	14272.23 25555.95	134.1 186.6	36.91 31.78	74.32 47.60	950. 262.
216.	.83417	17.601 .54264	12.304 1.278	.815 .005	14299.61 24032.10	14347.00 25569.34	134.5 186.4	36.92 31.92	74.60 48.00	941. 262.
217.	.86368	17.537 .56156	12.041 1.272	.805 .005	14372.80 24044.27	14422.05 25582.29	134.8 186.2	36.94 32.05	74.88 48.41	933. 262.
218.	.89395	17.472 .58100	11.780 1.265	.794 .006	14446.20 24056.15	14497.36 25594.77	135.1 186.1	36.96 32.19	75.18 48.83	924. 262.
219.	.92497	17.407 .60099	11.521 1.258	.783 .006	14519.83 24067.71	14572.97 25606.79	135.5 185.9	36.98 32.33	75.49 49.26	916. 261.
220.	.95678	17.342 .62154	11.263 1.250	.773 .006	14593.69 24078.96	14648.86 25618.33	135.8 185.7	37.00 32.47	75.80 49.71	907. 261.
221.	.98937	17.276 .64266	11.007 1.242	.762 .006	14667.79 24089.88	14725.06 25629.37	136.2 185.5	37.02 32.61	76.13 50.17	898. 261.
222.	1.0228	17.209 .66436	10.753 1.234	.752 .007	14742.13 24100.47	14801.56 25639.91	136.5 185.3	37.05 32.76	76.47 50.65	890. 261.
223.	1.0569	17.142 .68668	10.501 1.226	.742 .007	14816.73 24110.72	14878.39 25649.94	136.8 185.1	37.07 32.91	76.83 51.14	881. 261.
224.	1.0920	17.075 .70961	10.251 1.217	.731 .007	14891.60 24120.61	14955.55 25659.44	137.2 185.0	37.10 33.06	77.20 51.64	872. 260.
225.	1.1278	17.006 .73319	10.002 1.208	.721 .007	14966.74 24130.15	15033.05 25668.40	137.5 184.8	37.13 33.21	77.58 52.16	863. 260.
226.	1.1645	16.938 .75741	9.756 1.199	.711 .008	15042.16 24139.31	15110.91 25676.90	137.8 184.6	37.17 33.36	77.98 52.70	854. 260.
227.	1.2021	16.868 .78231	9.511 1.189	.701 .008	15117.87 24148.10	15189.13 25684.64	138.2 184.4	37.20 33.51	78.39 53.26	845. 260.
228.	1.2405	16.798 .80791	9.268 1.179	.691 .008	15193.88 24156.48	15267.73 25691.89	138.5 184.2	37.24 33.67	78.82 53.84	836. 259.
229.	1.2798	16.728 .83422	9.027 1.169	.681 .009	15270.21 24164.47	15346.72 25699.55	138.8 184.0	37.28 33.83	79.26 54.44	827. 259.
230.	1.3199	16.656 .86127	8.788 1.158	.670 .009	15346.86 24172.03	15426.11 25704.59	139.2 183.9	37.32 33.99	79.73 55.06	818. 259.
231.	1.3610	16.584 .88908	8.551 1.147	.660 .009	15423.84 24179.16	15505.91 25710.00	139.5 183.7	37.36 34.15	80.21 55.70	809. 258.
232.	1.4030	16.512 .91767	8.316 1.136	.651 .010	15501.17 24185.85	15586.14 25714.76	139.9 183.5	37.40 34.32	80.71 56.37	800. 258.
233.	1.4460	16.438 .94707	8.084 1.124	.641 .010	15578.86 24192.08	15666.82 25718.85	140.2 183.3	37.45 34.49	81.23 57.07	791. 257.

Table B-1. (Continued)

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of sound m/s
234.	1.4898	16.364 .97731	7.853 1.112	.631 .010	15655.92 24197.83	15747.96 25722.26	140.5 183.1	37.50 34.66	81.77 57.79	781. 257.
235.	1.5347	16.289 1.0084	7.624 1.100	.621 .011	15735.36 24203.10	15829.57 25724.96	140.9 183.0	37.55 34.83	82.34 58.54	772. 257.
236.	1.5804	16.213 1.0404	7.398 1.087	.611 .011	15814.19 24207.85	15911.68 25726.92	141.2 182.8	37.61 35.01	82.93 59.32	763. 256.
237.	1.6272	16.136 1.0733	7.173 1.074	.601 .011	15893.44 24212.08	15994.29 25728.14	141.5 182.6	37.66 35.18	83.55 60.14	753. 256.
238.	1.6750	16.058 1.1072	6.951 1.060	.592 .012	15973.12 24215.77	16077.42 25728.59	141.9 182.4	37.72 35.36	84.19 60.99	744. 255.
239.	1.7237	15.980 1.1420	6.731 1.046	.582 .012	16053.24 24218.89	16161.11 25728.23	142.2 182.2	37.78 35.55	84.86 61.87	734. 255.
240.	1.7735	15.900 1.1779	6.514 1.032	.572 .013	16133.81 24221.43	16245.35 25727.05	142.5 182.1	37.85 35.73	85.57 62.80	725. 254.
241.	1.8243	15.819 1.2149	6.299 1.018	.563 .013	16214.86 24223.36	16330.18 25725.01	142.9 181.9	37.91 35.92	86.30 63.77	715. 254.
242.	1.8761	15.738 1.2529	6.086 1.003	.553 .014	16296.40 24224.66	16415.62 25722.08	143.2 181.7	37.98 36.12	87.07 64.79	705. 253.
243.	1.9290	15.655 1.2921	5.876 .987	.543 .014	16378.46 24225.31	16501.68 25718.25	143.6 181.5	38.05 36.31	87.87 65.86	695. 253.
244.	1.9830	15.571 1.3325	5.668 .971	.534 .015	16461.05 24225.27	16588.40 25713.46	143.9 181.3	38.13 36.51	88.72 66.98	686. 252.
245.	2.0380	15.486 1.3741	5.463 .955	.524 .015	16544.19 24224.52	16675.79 25707.69	144.3 181.1	38.21 36.71	89.60 68.16	676. 251.
246.	2.0942	15.399 1.4170	5.260 .939	.515 .016	16627.90 24223.03	16763.89 25700.89	144.6 180.9	38.29 36.92	90.53 69.40	666. 251.
247.	2.1514	15.312 1.4613	5.060 .922	.505 .016	16712.21 24220.77	16852.72 25693.03	144.9 180.7	38.38 37.13	91.51 70.71	656. 250.
248.	2.2098	15.222 1.5070	4.863 .905	.496 .017	16797.14 24217.70	16942.31 25684.07	145.3 180.5	38.46 37.35	92.54 72.10	646. 250.
249.	2.2694	15.132 1.5542	4.668 .887	.486 .018	16882.73 24213.78	17032.70 25673.96	145.6 180.3	38.56 37.56	93.63 73.56	636. 249.
250.	2.3300	15.040 1.6029	4.476 .869	.477 .018	16968.99 24208.98	17123.91 25662.64	146.0 180.1	38.65 37.79	94.78 75.12	625. 248.
251.	2.3919	14.946 1.6532	4.287 .850	.467 .019	17055.95 24203.25	17215.99 25650.08	146.3 179.9	38.75 38.01	95.99 76.77	615. 247.
252.	2.4549	14.851 1.7052	4.101 .831	.458 .020	17143.66 24196.55	17308.96 25636.20	146.7 179.7	38.86 38.25	97.27 78.52	605. 247.
253.	2.5192	14.754 1.7590	3.917 .812	.448 .020	17232.13 24188.82	17402.88 25620.95	147.0 179.5	38.97 38.48	98.64 80.39	595. 246.
254.	2.5846	14.655 1.8147	3.737 .792	.439 .021	17321.42 24180.01	17497.78 25604.26	147.4 179.3	39.08 38.72	100.09 82.39	584. 245.
255.	2.6513	14.554 1.8724	3.559 .772	.430 .022	17411.56 24170.07	17593.72 25586.06	147.8 179.1	39.20 38.97	101.63 84.53	574. 244.

Table B-1. (Continued)

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ ·MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of sound m/s
256.	2.7192	14.451 1.9322	3.385 .751	.420 .023	17502.59 24158.92	17690.75 25566.26	148.1 178.9	39.32 39.22	103.28 86.83	563. 243.
257.	2.7884	14.346 1.9942	3.214 .730	.411 .024	17594.55 24146.50	17788.92 25544.80	148.5 178.7	39.45 39.48	105.05 89.31	552. 243.
258.	2.8589	14.239 2.0585	3.045 .709	.401 .025	17687.52 24132.73	17888.30 25521.55	148.9 178.4	39.59 39.75	106.94 91.98	542. 242.
259.	2.9307	14.129 2.1254	2.880 .687	.392 .026	17781.53 24117.53	17988.95 25496.44	149.2 178.2	39.73 40.02	108.98 94.87	531. 241.
260.	3.0039	14.017 2.1949	2.718 .664	.383 .027	17876.65 24100.79	18090.95 25469.33	149.6 178.0	39.88 40.29	111.19 98.02	520. 240.
261.	3.0783	13.902 2.2673	2.559 .642	.373 .028	17972.96 24082.42	18194.39 25440.10	150.0 177.7	40.03 40.58	113.59 101.45	509. 239.
262.	3.1542	13.784 2.3428	2.403 .619	.364 .029	18070.53 24062.30	18299.35 25408.61	150.4 177.5	40.19 40.87	116.19 105.21	498. 238.
263.	3.2314	13.663 2.4216	2.250 .594	.354 .030	18169.45 24040.29	18405.96 25374.70	150.7 177.2	40.37 41.18	119.05 109.35	486. 237.
264.	3.3100	13.538 2.5039	2.101 .570	.345 .031	18269.82 24016.25	18514.31 25338.18	151.1 177.0	40.54 41.49	122.19 113.92	475. 236.
265.	3.3900	13.410 2.5901	1.954 .545	.336 .033	18371.76 23990.01	18624.56 25298.84	151.5 176.7	40.73 41.81	125.67 119.01	464. 235.
5.	3.4715	13.277 2.6806	1.811 .520	.326 .034	18475.40 23961.37	18736.87 25256.45	151.9 176.4	40.93 42.14	129.54 124.70	452. 234.
7.	3.5545	13.140 2.7756	1.672 .494	.317 .036	18580.90 23930.10	18851.41 25210.73	152.3 176.1	41.14 42.48	133.88 131.11	440. 233.
3.	3.6390	12.998 2.8758	1.535 .468	.307 .037	18688.45 23895.95	18968.41 25161.35	152.7 175.8	41.37 42.83	138.80 138.39	428. 232.
3.	3.7250	12.851 2.9816	1.402 .441	.297 .039	18798.26 23858.58	19088.13 25107.93	153.2 175.5	41.61 43.20	144.42 146.73	416. 231.
3.	3.8126	12.697 3.0937	1.272 .413	.288 .041	18910.61 23817.64	19210.87 25050.01	153.6 175.2	41.86 43.57	150.91 156.39	404. 230.
.	3.9018	12.537 3.2130	1.145 .385	.278 .043	19025.82 23772.66	19337.04 24987.03	154.0 174.9	42.13 43.97	158.51 167.71	392. 229.
.	3.9926	12.369 3.3405	1.022 .356	.268 .045	19144.30 23723.08	19467.10 24918.29	154.5 174.5	42.42 44.38	167.54 181.16	379. 228.
.	4.0850	12.191 3.4774	.902 .326	.258 .047	19266.59 23666.17	19601.67 24842.90	155.0 174.1	42.73 44.81	178.47 197.44	367. 226.
.	4.1792	12.002 3.6255	.786 .296	.248 .049	19393.37 23607.02	19741.56 24759.75	155.4 173.7	43.07 45.26	192.01 217.56	353. 225.
.	4.2751	11.801 3.7869	.673 .264	.238 .052	19525.57 23538.38	19887.84 24667.29	155.9 173.3	43.44 45.74	209.24 243.07	340. 224.
.	4.3728	11.582 3.9648	.564 .232	.227 .055	19664.49 23460.55	20042.02 24563.45	156.5 172.8	43.85 46.25	231.97 276.56	326. 222.
.	4.4724	11.343 4.1638	.459 .199	.216 .059	19812.04 23371.06	20206.32 24445.17	157.0 172.3	44.30 46.79	263.38 322.52	312. 221.

Table B-1. (Continued)

Temp. K	Pressure MPa	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of sound m/s
278.	4.5739	11.076	.358	.205	19971.24	20384.20	157.6	44.83	309.74	297.
		4.3907	.164	.062	23266.09	24307.81	171.8	47.37	389.63	219.
279.	4.6774	10.768	.262	.192	20147.21	20581.61	158.3	45.44	385.16	282.
		4.6574	.128	.067	23139.26	24143.55	171.1	48.01	497.11	218.
280.	4.7831	10.394	.172	.179	20350.16	20810.31	159.1	46.19	529.36	265.
		4.9869	.091	.073	22978.35	23937.47	170.3	48.72	697.18	216.
281.	4.8910	9.895	.088	.163	20606.09	21100.40	160.1	47.20	911.93	247.
		5.4348	.053	.080	22754.05	23653.99	169.2	49.55	1197.30	214.
282.	5.0017	8.956	.016	.139	21049.80	21608.28	161.9	48.99	4431.04	224.
		6.2349	.015	.093	22347.15	23149.35	167.3	50.55	4272.17	212.

Table B-2. Thermodynamic Properties of Ethylene

.05 megapascal isobar

Temp. K	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of Sound m/s
*103.993	23.390	45.998	2.908	6614.60	6616.74	84.4	39.49	74.43	1758.
110.0	23.052	50.235	2.587	7044.44	7046.61	88.4	42.19	69.76	1721.
120.0	22.573	49.309	2.256	7729.74	7731.96	94.4	43.41	67.72	1656.
130.0	22.122	45.249	2.032	8402.41	8404.67	99.8	42.71	66.94	1590.
140.0	21.669	40.384	1.850	9070.17	9072.48	104.7	41.43	66.70	1522.
150.0	21.203	35.520	1.687	9737.71	9740.07	109.3	40.14	66.87	1452.
*158.297	20.802	31.719	1.559	10293.90	10296.30	112.9	39.21	67.23	1392.
*158.297	.038789	1.262	.000332	22985.93	24274.96	201.2	26.40	35.60	246.
160.0	.038347	1.277	.000328	23031.63	24335.51	201.6	26.39	35.56	248.
170.0	.035953	1.368	.000305	23299.50	24690.19	203.8	26.45	35.41	256.
180.0	.033859	1.457	.000286	23567.72	25044.41	205.8	26.63	35.46	263.
190.0	.032007	1.545	.000270	23837.72	25399.86	207.7	26.92	35.65	270.
200.0	.030355	1.631	.000255	24110.70	25757.85	209.6	27.31	35.97	277.
210.0	.028871	1.718	.000242	24387.68	26119.54	211.3	27.78	36.39	283.
220.0	.027528	1.803	.000231	24669.55	26485.87	213.0	28.34	36.90	289.
230.0	.026308	1.889	.000220	24957.12	26857.71	214.7	28.96	37.49	295.
240.0	.025193	1.974	.000211	25251.09	27235.81	216.3	29.65	38.15	301.
245.0	.024670	2.016	.000206	25400.69	27427.42	217.1	30.01	38.50	304.
250.0	.024170	2.059	.000202	25552.12	27620.84	217.9	30.39	38.87	306.
256.0	.023595	2.110	.000197	25736.37	27855.43	218.8	30.87	39.33	310.
258.0	.023410	2.127	.000196	25798.41	27934.26	219.1	31.03	39.49	311.
260.0	.023227	2.144	.000194	25860.78	28013.40	219.4	31.19	39.65	312.
262.0	.023048	2.160	.000192	25923.47	28092.85	219.7	31.36	39.81	313.
264.0	.022871	2.177	.000191	25986.49	28172.64	220.0	31.52	39.98	314.
266.0	.022697	2.194	.000189	26049.84	28252.77	220.3	31.69	40.14	315.
268.0	.022526	2.211	.000188	26113.53	28333.22	220.6	31.86	40.31	316.
270.0	.022357	2.228	.000187	26177.56	28414.01	220.9	32.04	40.48	317.
275.0	.021946	2.270	.000183	26339.14	28617.48	221.7	32.47	40.91	319.
280.0	.021550	2.312	.000180	26502.91	28823.12	222.4	32.92	41.35	322.
285.0	.021168	2.355	.000177	26668.92	29030.98	223.1	33.37	41.80	324.
290.0	.020800	2.397	.000174	26837.21	29241.11	223.9	33.83	42.25	327.
295.0	.020444	2.439	.000171	27007.81	29453.54	224.6	34.30	42.72	329.
300.0	.020100	2.481	.000168	27180.76	29668.31	225.3	34.78	43.19	331.
305.0	.019768	2.523	.000165	27356.10	29885.45	226.0	35.26	43.67	334.
310.0	.019447	2.565	.000162	27533.83	30104.99	226.7	35.75	44.15	336.
320.0	.018834	2.649	.000157	27896.62	30551.34	228.2	36.73	45.13	341.
330.0	.018260	2.733	.000152	28269.27	31007.53	229.6	37.72	46.11	345.
340.0	.017719	2.817	.000148	28651.90	31473.67	231.0	38.73	47.11	349.
350.0	.017210	2.900	.000143	29044.55	31949.81	232.3	39.74	48.12	354.
360.0	.016730	2.984	.000139	29447.27	32435.98	233.7	40.74	49.12	358.
370.0	.016275	3.068	.000136	29860.05	32932.20	235.1	41.75	50.12	362.
380.0	.015845	3.152	.000132	30282.84	33438.41	236.4	42.75	51.12	367.
390.0	.015437	3.235	.000129	30715.61	33954.58	237.8	43.75	52.11	371.
400.0	.015050	3.319	.000125	31158.28	34480.64	239.1	44.74	53.10	375.
425.0	.014161	3.528	.000118	32307.75	35838.52	242.4	47.17	55.52	385.
450.0	.013372	3.737	.000111	33517.26	37256.37	245.6	49.55	57.90	395.

* Saturated state

Table B-2. (Continued)

.10 megapascal isobar

Temp. K	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of Sound m/s
*104.000	23.391	45.989	2.907	6614.52	6618.80	84.4	39.51	74.45	1758.
110.0	23.053	50.232	2.587	7043.90	7048.24	88.4	42.20	69.77	1721.
120.0	22.574	49.318	2.256	7729.21	7733.64	94.4	43.42	67.72	1656.
130.0	22.123	45.264	2.032	8401.81	8406.33	99.8	42.71	66.93	1590.
140.0	21.670	40.403	1.850	9069.49	9074.10	104.7	41.43	66.70	1523.
150.0	21.204	35.540	1.687	9736.92	9741.63	109.3	40.15	66.87	1453.
160.0	20.720	30.994	1.533	10407.53	10412.36	113.6	39.04	67.32	1380.
*169.186	20.256	27.184	1.399	11028.38	11033.31	117.4	38.24	67.90	1312.
*169.186	.073548	1.312	.000640	23221.29	24580.95	197.5	27.11	36.86	252.
170.0	.073154	1.320	.000636	23243.94	24610.92	197.7	27.10	36.82	253.
180.0	.068674	1.416	.000591	23521.24	24977.38	199.8	27.11	36.52	261.
190.0	.064764	1.508	.000553	23798.09	25342.17	201.7	27.28	36.47	268.
200.0	.061308	1.599	.000521	24076.35	25707.46	203.6	27.58	36.61	275.
210.0	.058226	1.689	.000493	24357.47	26074.93	205.4	28.00	36.90	282.
220.0	.055454	1.777	.000468	24642.64	26445.94	207.1	28.50	37.32	288.
230.0	.052945	1.865	.000446	24932.88	26821.62	208.8	29.09	37.83	294.
240.0	.050662	1.952	.000426	25229.04	27202.92	210.4	29.75	38.44	300.
245.0	.049595	1.996	.000417	25379.58	27395.94	211.2	30.10	38.77	303.
250.0	.048573	2.039	.000408	25531.88	27590.65	212.0	30.47	39.12	305.
256.0	.047402	2.091	.000398	25717.07	27826.67	212.9	30.94	39.56	309.
258.0	.047025	2.108	.000394	25779.41	27905.94	213.3	31.10	39.71	310.
260.0	.046654	2.125	.000391	25842.06	27985.51	213.6	31.26	39.86	311.
262.0	.046288	2.142	.000388	25905.03	28065.39	213.9	31.42	40.02	312.
264.0	.045929	2.160	.000385	25968.31	28145.59	214.2	31.58	40.18	313.
266.0	.045575	2.177	.000382	26031.95	28226.11	214.5	31.75	40.34	314.
268.0	.045227	2.194	.000379	26095.87	28306.94	214.8	31.92	40.50	315.
270.0	.044884	2.211	.000376	26160.14	28388.11	215.1	32.09	40.66	316.
275.0	.044050	2.254	.000369	26322.29	28592.45	215.8	32.52	41.08	319.
280.0	.043246	2.297	.000362	26486.60	28798.95	216.6	32.96	41.51	321.
285.0	.042472	2.339	.000356	26653.11	29007.60	217.3	33.41	41.95	324.
290.0	.041726	2.382	.000349	26821.86	29218.46	218.0	33.87	42.40	326.
295.0	.041005	2.425	.000343	26992.90	29431.59	218.8	34.34	42.85	328.
300.0	.040310	2.467	.000337	27166.26	29647.02	219.5	34.81	43.32	331.
305.0	.039638	2.510	.000332	27341.97	29864.79	220.2	35.29	43.79	333.
310.0	.038989	2.552	.000326	27520.07	30084.91	220.9	35.77	44.26	336.
320.0	.037752	2.637	.000316	27883.52	30532.36	222.4	36.75	45.23	340.
330.0	.036593	2.722	.000306	28256.78	30989.55	223.8	37.74	46.21	345.
340.0	.035503	2.806	.000297	28639.94	31456.59	225.2	38.74	47.20	349.
350.0	.034477	2.891	.000288	29033.10	31933.57	226.5	39.75	48.20	353.
360.0	.033509	2.975	.000280	29436.27	32420.52	227.9	40.76	49.19	358.
370.0	.032595	3.060	.000272	29849.46	32917.45	229.3	41.76	50.19	362.
380.0	.031729	3.144	.000265	30272.65	33424.33	230.6	42.76	51.18	366.
390.0	.030909	3.228	.000258	30705.78	33941.13	232.0	43.76	52.17	370.
400.0	.030130	3.312	.000251	31148.79	34467.77	233.3	44.74	53.15	375.
425.0	.028345	3.522	.000236	32299.03	35826.97	236.6	47.18	55.57	385.
450.0	.026761	3.732	.000223	33509.22	37245.98	239.8	49.55	57.94	394.

* Saturated state

Table B-2. (Continued)

.101325 megapascal Isobar

Temp. K	Density mol/dm ³	Isotherm Derivative dm ³ -MPa/mol	Isochore Derivative MPa/K	Internal Energy J/mol	Enthalpy J/mol	Entropy J/(mol·K)	C _v J/(mol·K)	C _p J/(mol·K)	Velocity of Sound m/s
*104.000	23.391	45.988	2.907	6614.52	6618.85	84.4	39.51	74.45	1758.
110.0	23.053	50.232	2.587	7043.89	7048.28	88.4	42.20	69.77	1721.
120.0	22.574	49.318	2.256	7729.19	7733.68	94.4	43.42	67.72	1656.
130.0	22.123	45.264	2.032	8401.80	8406.38	99.8	42.71	66.93	1590.
140.0	21.670	40.403	1.850	9069.47	9074.14	104.7	41.43	66.70	1523.
150.0	21.204	35.540	1.687	9736.90	9741.67	109.3	40.15	66.87	1453.
160.0	20.720	30.994	1.533	10407.51	10412.40	113.6	39.05	67.32	1380.
*169.409	20.245	27.096	1.395	11043.53	11048.54	117.5	38.22	67.92	1310.
*169.409	.074448	1.313	.000649	23225.98	24587.00	197.4	27.13	36.89	252.
170.0	.074159	1.319	.000645	23242.44	24608.76	197.6	27.12	36.86	253.
180.0	.069611	1.414	.000599	23519.98	24975.57	199.7	27.13	36.55	261.
190.0	.065642	1.507	.000561	23797.03	25340.62	201.6	27.29	36.49	268.
200.0	.062137	1.598	.000528	24075.43	25706.11	203.5	27.59	36.63	275.
210.0	.059010	1.688	.000500	24356.66	26073.74	205.3	28.00	36.92	282.
220.0	.056200	1.777	.000474	24641.93	26444.88	207.0	28.51	37.33	288.
230.0	.053656	1.865	.000452	24932.23	26820.66	208.7	29.09	37.84	294.
240.0	.051340	1.952	.000432	25228.45	27202.04	210.3	29.75	38.45	300.
245.0	.050259	1.995	.000422	25379.02	27395.10	211.1	30.11	38.78	303.
250.0	.049223	2.038	.000413	25531.34	27589.85	211.9	30.48	39.13	305.
256.0	.048036	2.090	.000403	25716.56	27825.90	212.8	30.94	39.56	309.
258.0	.047654	2.107	.000400	25778.90	27905.18	213.1	31.10	39.72	310.
260.0	.047277	2.125	.000397	25841.56	27984.77	213.5	31.26	39.87	311.
262.0	.046907	2.142	.000393	25904.54	28064.66	213.8	31.42	40.02	312.
264.0	.046543	2.159	.000390	25967.83	28144.87	214.1	31.59	40.18	313.
266.0	.046184	2.176	.000387	26031.45	28225.40	214.4	31.75	40.34	314.
268.0	.045831	2.193	.000384	26095.40	28306.24	214.7	31.92	40.50	315.
270.0	.045483	2.211	.000381	26159.67	28387.42	215.0	32.09	40.67	316.
275.0	.044638	2.253	.000374	26321.84	28591.78	215.7	32.52	41.09	319.
280.0	.043823	2.296	.000367	26486.17	28798.30	216.5	32.96	41.52	321.
285.0	.043038	2.339	.000360	26652.69	29006.97	217.2	33.41	41.95	324.
290.0	.042282	2.382	.000354	26821.45	29217.86	217.9	33.87	42.40	326.
295.0	.041552	2.424	.000348	26992.50	29431.01	218.7	34.34	42.86	328.
300.0	.040847	2.467	.000342	27165.87	29646.46	219.4	34.81	43.32	331.
305.0	.040166	2.509	.000336	27341.60	29864.24	220.1	35.29	43.79	333.
310.0	.039508	2.552	.000330	27519.71	30084.38	220.8	35.77	44.27	336.
320.0	.038255	2.637	.000320	27883.18	30531.86	222.2	36.75	45.23	340.
330.0	.037080	2.722	.000310	28256.45	30989.07	223.7	37.74	46.21	345.
340.0	.035975	2.806	.000301	28639.63	31456.14	225.0	38.74	47.20	349.
350.0	.034936	2.891	.000292	29032.79	31933.14	226.4	39.75	48.20	353.
360.0	.033955	2.975	.000284	29435.98	32420.11	227.8	40.76	49.20	358.
370.0	.033028	3.059	.000276	29849.18	32917.06	229.2	41.76	50.19	362.
380.0	.032151	3.144	.000268	30272.38	33423.96	230.5	42.76	51.19	366.
390.0	.031319	3.228	.000261	30705.52	33940.77	231.9	43.76	52.17	370.
400.0	.030530	3.312	.000255	31148.54	34467.43	233.2	44.75	53.16	375.
425.0	.028721	3.522	.000240	32298.80	35826.67	236.5	47.18	55.57	385.
450.0	.027116	3.732	.000226	33509.00	37245.70	239.7	49.55	57.94	394.

* Saturated state