



ESDU 02004

Issued May 2002
With Amendment A
May 2003
Supersedes in part
ESDU 91005

**Thermal conductivity, viscosity,
isobaric specific heat capacity and
Prandtl number of gases at low
pressure: Halogenated hydrocarbons
– haloethanes**

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THE PREPARATION OF THIS DATA ITEM

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THERMAL CONDUCTIVITY, VISCOSITY, ISOBARIC SPECIFIC HEAT CAPACITY AND PRANDTL NUMBER OF GASES AT LOW PRESSURE: HALOGENATED HYDROCARBONS – HALOETHANES

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Data sheets for each of the gases are given in the following order:-

Formula	Name	Alternative Name(s)
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MONOHALOETHANES

1.	C ₂ H ₅ Cl	Chloroethane	Ethyl chloride	Refrigerant 160	11
2.	C ₂ H ₅ Br	Bromoethane	Ethyl bromide	Refrigerant 160B1	12
3.	C ₂ H ₅ I	Iodoethane	Ethyl iodide		13

Formula	Name	Alternative Name(s)
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DIHALOETHANES

4.	CHF_2CH_3	1,1-Difluoroethane	Ethylidene fluoride	Refrigerant 152a	14
5.	$(\text{CH}_2\text{F})_2$	1,2-Difluoroethane	Ethylene difluoride	Refrigerant 152	15
6.	CHCl_2CH_3	1,1-Dichloroethane	Ethylidene chloride	Refrigerant 150a	16
7.	$(\text{CH}_2\text{Cl})_2$	1,2-Dichloroethane	Ethylene dichloride	Refrigerant 150	17
8.	$(\text{CH}_2\text{Br})_2$	1,2-Dibromoethane	Ethylene dibromide	Refrigerant 150B2	18

TRIALOETHANES

9.	CF_3CH_3	1,1,1-Trifluoroethane	Methyl fluoroform	Refrigerant 143a	19
10.	$\text{CHF}_2\text{CH}_2\text{F}$	1,1,2-Trifluoroethane		Refrigerant 143	20
11.	CClF_2CH_3	1-Chloro-1,1-difluoroethane		Refrigerant 142b	21
12.	$\text{CHF}_2\text{CH}_2\text{Cl}$	2-Chloro-1,1-difluoroethane		Refrigerant 142	22
13.	CCl_2FCH_3	1,1-Dichloro-1-fluoroethane		Refrigerant 141b	23
14.	CCl_3CH_3	1,1,1-Trichloroethane	Methyl chloroform	Refrigerant 140a	24
15.	$\text{CHCl}_2\text{CH}_2\text{Cl}$	1,1,2-Trichloroethane		Refrigerant 140	25
16.	$\text{CHBr}_2\text{CH}_2\text{Br}$	1,1,2-Tribromoethane		Refrigerant 140B3	26

TETRAHALOETHANES

17.	$\text{CF}_3\text{CH}_2\text{F}$	1,1,1,2-Tetrafluoroethane		Refrigerant 134a	27
18.	$(\text{CHF}_2)_2$	1,1,2,2-Tetrafluoroethane	Acetylene tetrafluoride	Refrigerant 134	28
19.	$\text{CF}_3\text{CH}_2\text{Cl}$	2-Chloro-1,1,1-trifluoroethane		Refrigerant 133a	29
20.	$\text{CClF}_2\text{CH}_2\text{Cl}$	1,2-Dichloro-1,1-difluoroethane		Refrigerant 132b	30
21.	$\text{CCl}_3\text{CH}_2\text{Cl}$	1,1,1,2-Tetrachloroethane		Refrigerant 130a	31
22.	$(\text{CHCl}_2)_2$	1,1,2,2-Tetrachloroethane	Acetylene tetrachloride	Refrigerant 130	32

PENTAHALOETHANES

23.	C_2HF_5	Pentafluoroethane		Refrigerant 125	33
24.	$\text{CClF}_2\text{CHF}_2$	Chloro-1,1,2,2-tetrafluoroethane		Refrigerant 124a	34
25.	CF_3CHClF	Chloro-1,1,1,2-tetrafluoroethane		Refrigerant 124	35
26.	$\text{CClF}_2\text{CHClF}$	1,2-Dichloro-1,1,2-trifluoroethane		Refrigerant 123a	36
27.	CF_3CHCl_2	2,2-Dichloro-1,1,1-trifluoroethane		Refrigerant 123	37
28.	C_2HCl_5	Pentachloroethane		Refrigerant 120	38

HEXAHALOETHANES

29.	C_2F_6	Hexafluoroethane	Perfluoroethane	Refrigerant 116	39
30.	C_2ClF_5	Chloropentafluoroethane		Refrigerant 115	40
31.	CCl_2FCF_3	1,1-Dichlorotetrafluoroethane		Refrigerant 114a	41

	Formula	Name	Alternative Name(s)	
32.	$(\text{CClF}_2)_2$	1,2-Dichlorotetrafluoroethane	Refrigerant 114	42
33.	$(\text{CBrF}_2)_2$	1,2-Dibromotetrafluoroethane	Refrigerant 114B2	43
34.	CCl_3CF_3	1,1,1-Trichlorotrifluoroethane	Refrigerant 113a	44
35.	$\text{CCl}_2\text{FCClF}_2$	1,1,2-Trichlorotrifluoroethane	Refrigerant 113	45
36.	$(\text{CCl}_2\text{F})_2$	Tetrachloro-1,2-difluoroethane	Refrigerant 112	46

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THERMAL CONDUCTIVITY, VISCOSITY, ISOBARIC SPECIFIC HEAT CAPACITY AND PRANDTL NUMBER OF GASES AT LOW PRESSURE: HALOGENATED HYDROCARBONS – HALOETHANES

1. INTRODUCTION

This Item presents in tabular form values of thermal conductivity, viscosity, isobaric specific heat capacity and Prandtl number of the vapours of haloethanes at or below atmospheric pressure. The range covered is from below the normal boiling point to at least 603 K. Previous Data Items in this group were restricted to thermal conductivity but the importance of the Prandtl number for chemical engineering design makes the inclusion of the isobaric specific heat capacity and viscosity desirable.

The data on which these values are based are believed to be the most reliable available and have been reviewed and suitably extended. Sections 4, 5 and 6 describe, respectively, the procedures used to obtain the values of thermal conductivity, viscosity and isobaric specific heat capacity and indicate the effects of pressure. Section 7 gives an explanation of the Tables, the Prandtl number equation and indicates the uncertainties in the values presented.

References to sources of supplementary information are given in Section 8. Appendix A provides a full bibliography of relevant data sources for viscosity, specific heat capacity and thermal conductivity. The data sources for each particular compound are listed with the appropriate table.

2. NOTATION AND UNITS

The units of each property are based on SI units. The SI units of thermal conductivity, viscosity and specific heat capacity are the watt per metre kelvin (W/m K), the newton second per square metre (N s/m²) and the joule per kilogram kelvin (J/kg K) respectively. Convenient units for the properties in this Item are: thermal conductivity, the milliwatt per metre kelvin (mW/m K); viscosity, the micronewton second per square metre (μN s/m²); isobaric specific heat capacity, the kilojoule per kilogram kelvin (kJ/kg K). Conversion factors are given in Section 3. The correlation parameters are not dimensionless but take the units listed in Tables 9.1, 9.2 and 9.3.

b_1, b_2, b_3, b_4	constants for each fluid in Equation (4.1), (5.1), (6.1)	*
c	specific heat capacity	kJ/kg K
M	molecular weight (relative molecular mass)	—
p	pressure	kPa
Pr	Prandtl number	—
T	kelvin temperature	K
t	Celsius temperature, $T-273.15$	°C
η	dynamic viscosity	μN s/m ²
λ	thermal conductivity	mW/m K

* See footnote at end of this section.

Superscripts

id	denotes ideal gas
(o)	denotes dilute gas

Subscripts

c	denotes value at critical point
p	denotes constant pressure
r	denotes reduced quantity, for example $T_r = T/T_c$.

* The units of these constants for thermal conductivity, viscosity and ideal gas heat capacity can be found in Tables 9.1, 9.2 and 9.3 respectively.

3. CONVERSION FACTORS

Thermal conductivity

$$\begin{aligned}
 1 \text{ mW/m K} &= 0.8598 \times 10^{-3} \text{ kcal/m h } ^\circ\text{C} \\
 &= 2.3885 \times 10^{-6} \text{ cal/cm s } ^\circ\text{C} \\
 &= 0.5778 \times 10^{-3} \text{ Chu/ft h } ^\circ\text{C} \\
 &= 0.5778 \times 10^{-3} \text{ Btu/ft h } ^\circ\text{F} \\
 &= 6.9335 \times 10^{-3} \text{ Btu in/ft}^2 \text{ h } ^\circ\text{F}
 \end{aligned}$$

Viscosity

$$\begin{aligned}
 1 \text{ } \mu\text{N s/m}^2 &= 10^{-3} \text{ cP} \\
 &= 145.04 \times 10^{-12} \text{ lbf s/in}^2 \\
 &= 101.972 \times 10^{-9} \text{ kgf s/m}^2 \\
 &= 10^{-6} \text{ kg/m s}
 \end{aligned}$$

Specific heat capacity

$$\begin{aligned}
 1 \text{ kJ/kg K} &= 0.239 \text{ cal/g K} \\
 &= 0.239 \text{ Btu/lb } ^\circ\text{F}
 \end{aligned}$$

Pressure

$$\begin{aligned}
 10^5 \text{ Pa} &= 1 \text{ bar} \\
 &= 14.5038 \text{ lbf/in}^2 \\
 &= 1.0197 \text{ kgf/cm}^2 \\
 &= 0.9869 \text{ atm} \\
 &= 750.062 \text{ mmHg.}
 \end{aligned}$$

4. THERMAL CONDUCTIVITY OF GASES

4.1 Thermal Conductivity at Low Pressure (Dilute Gas)

A comprehensive survey of the literature on the thermal conductivity of gases was prepared with the assistance of the National Engineering Laboratory (NEL), East Kilbride, UK. An attempt has been made to correlate the data between compounds in the same way as for the alkanes (Reference 26). The results given for the haloethanes in Data Item 91005 (Reference 18) were confirmed by the use of a prediction routine developed by NEL (Reference 17), and they are reproduced here unless more recent data were available to update them. Additional compounds have been evaluated with this routine which derives the

vapour thermal conductivity from the viscosity and the heat capacity.

Agreement of the data among the various authors and differing methods was reasonable and it was possible to extend the range of results to between at least 333 and 603 K in all cases, using the theoretical predictions.

The correlated data are represented by the equation

$$\lambda^{(o)} = b_1 + b_2(1 - T_r) + b_3(1 - T_r)^2 + b_4(1 - T_r)^3. \quad (4.1)$$

The derived values of the constants given in Table 9.1 give the best fits to the data.

Using these values with the values of T_c given in Table 9.1 (References 15, 19, 20), values of $\lambda^{(o)}$ in mW/m K have been calculated at 20 K and at 20 degree Celsius intervals for each compound.

4.2 Effect of Pressure

The thermal conductivity of all gases increases with pressure but the effect is small at low pressures from 0.1 to 1000 kPa (approximately 1% per 100 kPa). At higher pressures it is difficult to generalise. The correlations of Stiel and Thodos (Reference 3) remain the best method of evaluating the pressure effect in terms of the density and critical properties. Data for common refrigerants are available in References 14 and 16 and in the data sources marked with an asterisk in Appendix A2.

Near the critical point, the thermal conductivity increases asymptotically and at the critical point tends to infinity. This phenomenon, the so-called critical enhancement implies that, in the critical region the thermal conductivity is very sensitive to temperature and pressure and cannot be predicted reliably. As a rough guide, for the subcritical vapour for $0.9 \leq T_r \leq 1$, the critical enhancement takes effect at pressures exceeding $\approx 0.5p_c$ and is greatest at saturation. For values of T_r in the range $1 \leq T_r \leq 1.1$, the thermal conductivity at any specified temperature passes through a maximum at values of $p_r > 1$; the maximum declines and shifts to higher pressures with increasing temperature. For example, Data Source A2.: 961 gives tables for R152a that show the thermal conductivity close to the critical point to be 4.3 times its value at atmospheric pressure. A useful discussion of the anomalous behaviour of thermal conductivity near the critical point is given in References 21, 23 and Data Source A2.: 7512.

Tables providing data at various pressures up to the critical temperature are available for the following refrigerants: R113, R114, R134a and R152a (Data Sources Appendix A2).

5. VISCOSITY OF GASES

5.1 Viscosity at Low Pressure (Dilute Gas)

Well-documented and correlated data are available for a number of haloethane refrigerants and these data were extended to lower and/or higher temperatures by using the predictions based on theoretical considerations. The Reichenberg method (Reference 11) appeared to give adequate agreement with chlorinated compounds but was not reliable for compounds containing fluorine. An alternative prediction procedure based on the Chapman-Enskog theory is used by NEL (Reference 17) and requires the density of the liquid at the normal boiling point and the acentric factor. Fewer experimental viscosity data were available than for thermal conductivity, but the results using the method were adequate and successful in supporting the predictions for thermal conductivity. A number of fluorinated compounds, for which the required density and acentric factors were available from References 15 and 19, were therefore included in this Item.

The experimental and estimated dilute gas viscosities are adequately represented by the following equation of the same form as that used for thermal conductivity and it is valid over the same temperature range.

$$\eta^{(o)} = b_1 + b_2(1 - T_r) + b_3(1 - T_r)^2 + b_4(1 - T_r)^3. \quad (5.1)$$

The derived values of the constants given in Table 9.2 give the best fit to the data. Using these values with the value of T_c given in Table 9.2, values of $\eta^{(o)}$ in $\mu\text{N s/m}^2$ have been calculated at 20 K and at 20 degree Celsius intervals for each compound.

5.2 Effect of Pressure

The viscosity of gases increases with pressure, but the effect is small at low pressures (0.1 to 1000 kPa). The correlations of Stiel and Thodos (References 2, 4) may be used to evaluate the pressure effect in terms of the density and critical properties. Near the critical point, however, the pressure effect is greater and cannot be predicted reliably but is less significant than in the case of thermal conductivity.

Data for common refrigerants are available in References 24 and 25 and specifically in the data sources marked with an asterisk in Appendix A1.

6. ISOBARIC SPECIFIC HEAT CAPACITY

6.1 Isobaric Specific Heat Capacity at Low Pressure (Ideal Gas)

The isobaric specific heat capacity approaches the ideal gas value as the pressure tends to zero and these are the values tabulated in this Data Item.

Data for the isobaric specific heat capacity of the ideal gas were taken, with two exceptions, from Data Source A1.: 19. Over the temperature ranges covered by this Data Item, they can be adequately represented by the following simple polynomial in reduced temperature:

$$c_p^{\text{id}} = b_1 + b_2 T_r + b_3 T_r^2 + b_4 T_r^3. \quad (6.1)$$

The values of the constants given in Table 9.3 were derived from the best fit to the selected data over the given temperature range. Using these values with the value of T_c given in Table 9.3, values of c_p^{id} in kJ/kg K have been calculated at 20 K and at 20 degree Celsius intervals for each compound.

6.2 Effect of Pressure

For non-reacting non-associating vapours, far from the critical point, the effect of pressure is small. At the critical point c_p tends to infinity and large effects in the critical region will occur. Estimates may be obtained from general equations of state such as the Soave-Redlich-Kwong, Lee-Kesler and Peng-Robinson (References 9, 10, 13). Fortran programs for the Soave-Redlich-Kwong, and Peng-Robinson equations may be found in Reference 21.

For more accurate calculations, fluid specific equations of state should be used. References to these for 1,1,1,2-tetrafluoroethane and 1,1,2-trichlorotrifluoroethane may be found in a review article by de Reuck, Craven and Elhassan (Reference 22). For R123, R134a and R152a, equations of state are listed in Reference 25 and equations for other particular refrigerants are listed in References 21 and 25. Tables of specific enthalpy at saturation pressure for R123 and R134a are presented in Reference 16.

7. EXPLANATION OF TABLES AND THE PRANDTL NUMBER EQUATION

For each compound the constants in Equations (4.1), (5.1) and (6.1) are given in Tables 9.1, 9.2 and 9.3 respectively, together with the critical temperature and the range of applicability. Because of possible decomposition of these compounds the experimental data, where they exist, and the tables are limited to a maximum of 350 °C.

Within the compound tables, values of thermal conductivity and viscosity that are supported by experimental data are presented in bold type. Isobaric specific heat capacity values from Data Source A1.: 19 are also given in bold type.

Experimental data for thermal conductivity from the most reliable individual sources have a repeatability of about ±2%. However, differences in methods and technique increase the uncertainty of the absolute values to ±3% or more. Such reliable data are available for the principal refrigerants.

Although it is considered that the procedure adopted for thermal conductivity keeps the errors in the values presented to a minimum, the user should allow for an uncertainty of ±5% in all values, except those unsupported by experimental data (presented in plain type) where the uncertainty increases to ±10%.

Experimental data for the viscosity of the principal refrigerants have been reviewed, and the reliable data have a repeatability of about ±3%. For values unsupported by experiment the uncertainty is greater. Although it is considered that the procedure adopted here keeps the errors in the values presented to a minimum, the user should allow for an uncertainty of ±5% in all values.

Except for R150B2 and R114B2 the isobaric specific heat capacity values are based on tables published by the Thermodynamics Research Center (TRC). Comparisons with reliable experimental data indicate that the TRC values have uncertainties of ± 2%. For the compounds R150B2 and R114B2 uncertainties of ± 5% should be allowed for.

At any specific temperature, the Prandtl number entry was calculated from Equations (4.1), (5.1), (6.1) and the relation

$$Pr^{(o)} = \frac{c_p^{id} \eta^{(o)}}{\lambda^{(o)}}. \quad (7.1)$$

No attempt was made to smooth the values thus obtained. Rounding errors, which may affect the last significant figure may produce differences between the tabulated values and those calculated directly from the tabulated entries for thermal conductivity, viscosity and isobaric specific heat capacity.

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The references given are recommended sources of information supplementary to that in this Data Item.

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9. TABLES

TABLE 9.1 Dilute Gas Thermal Conductivity; Constants for Equation (4.1)

Compound		T_c	b_1	b_2	b_3	b_4	Range of applicability	
		K	mW/m K	mW/m K	mW/m K	mW/m K	°C	
1.	Chloroethane	460.	24.73	-43.28	14.75	4.80	-53	to 350
2.	Bromoethane	504.	23.07	-34.63	0	0	-33	to 330
3.	Iodoethane	563.	19.03	-29.90	2.79	9.92	-13	to 330
4.	1,1-Difluoroethane	386.55	22.56	-37.78	5.80	1.27	-33	to 350
5.	1,2-Difluoroethane	452.	27.55	-44.97	10.44	10.50	-53	to 350
6.	1,1-Dichloroethane	522.	23.54	-40.44	9.24	14.02	-13	to 350
7.	1,2-Dichloroethane	563.	25.27	-43.58	41.95	-44.66	-13	to 350
8.	1,2-Dibromoethane	645.	20.72	-28.10	-1.72	9.64	20	to 347
9.	1,1,1-Trifluoroethane	346.25	16.53	-30.31	9.32	8.99	-73	to 350
10.	1,1,2-Trifluoroethane	432.	25.96	-41.19	7.05	9.73	-73	to 350
11.	1-Chloro-1,1-difluoroethane	410.	19.28	-31.67	1.95	14.22	-33	to 350
12.	2-Chloro-1,1-difluoroethane	490.	24.86	-38.99	4.46	11.88	-33	to 350
13.	1,1-Dichloro-1-fluoroethane	473.	20.37	-31.72	2.26	9.01	-33	to 350
14.	1,1,1-Trichloroethane	545.	21.20	-28.93	-1.36	8.79	-13	to 350
15.	1,1,2-Trichloroethane	605.	23.47	-32.02	-9.08	22.04	20	to 347
16.	1,1,2-Tribromoethane	705.	17.31	-21.52	-4.08	8.46	60	to 347
17.	1,1,1,2-Tetrafluoroethane	374.25	19.46	-30.25	7.25	3.81	-53	to 350
18.	1,1,2,2-Tetrafluoroethane	384.	21.25	-31.12	4.50	4.80	-73	to 350
19.	2-Chloro-1,1,1-trifluoroethane	430.	20.47	-31.29	3.18	7.80	-53	to 350
20.	1,2-Dichloro-1,1-difluoroethane	495.	21.36	-30.07	0.18	8.96	-33	to 350
21.	1,1,1,2-Tetrachloroethane	610.	20.10	-25.84	-3.47	8.84	20	to 347
22.	1,1,2,2-Tetrachloroethane	635.	20.90	-26.82	-4.61	10.05	20	to 347
23.	Pentafluoroethane	339.4	17.25	-27.44	4.88	4.26	-73	to 350
24.	Chloro-1,1,2,2-tetrafluoroethane	400.	18.14	-26.81	2.26	5.85	-73	to 350
25.	Chloro-1,1,1,2-tetrafluoroethane	395.65	17.77	-26.88	2.68	5.95	-73	to 350
26.	1,2-Dichloro-1,1,2-trifluoroethane	458.3	18.89	-26.72	0.05	7.24	-53	to 350
27.	2,2-Dichloro-1,1,1-trifluoroethane	456.9	19.20	-26.87	0.43	7.64	-73	to 350
28.	Pentachloroethane	670.	18.35	-23.21	-7.55	13.04	20	to 347
29.	Hexafluoroethane	293.	14.21	-21.96	0	0	-93	to 350
30.	Chloropentafluoroethane	353.15	15.20	-22.92	0.65	0.06	-73	to 350
31.	1,1-Dichlorotetrafluoroethane	418.7	17.23	-24.05	0.09	5.72	-73	to 350
32.	1,2-Dichlorotetrafluoroethane	418.85	17.50	-23.00	0	0	-33	to 350
33.	1,2-Dibromotetrafluoroethane	488.	15.43	-17.53	0	0	-33	to 350
34.	1,1,1-Trichlorotrifluoroethane	486.	17.87	-23.44	-1.99	6.65	-33	to 350
35.	1,1,2-Trichlorotrifluoroethane	487.35	18.00	-24.00	0	0	-33	to 350
36.	Tetrachloro-1,2-difluoroethane	556.	18.45	-22.62	-3.84	6.06	20	to 347

TABLE 9.2 Dilute Gas Viscosity; Constants for Equation (5.1)

Compound		T_c	b_1	b_2	b_3	b_4	Range of applicability		
		K	$\mu\text{N s/m}^2$	$\mu\text{N s/m}^2$	$\mu\text{N s/m}^2$	$\mu\text{N s/m}^2$	°C		
1.	Chloroethane	460.	14.65	-13.31	-0.80	-2.11	-53	to	350
2.	Bromoethane	504.	19.37	-19.20	-2.41	2.67	-33	to	330
3.	Iodoethane	563.	22.11	-21.32	-4.08	3.91	-13	to	330
4.	1,1-Difluoroethane	386.55	13.48	-14.23	-1.75	6.97	-33	to	350
5.	1,2-Difluoroethane	452.	15.15	-14.79	-1.79	1.32	-53	to	350
6.	1,1-Dichloroethane	522.	16.42	-16.19	-2.09	2.17	-13	to	350
7.	1,2-Dichloroethane	563.	17.42	-17.06	-2.66	2.80	-13	to	350
8.	1,2-Dibromoethane	645.	22.90	-21.49	-2.71	1.23	20	to	347
9.	1,1,1-Trifluoroethane	346.25	13.52	-14.07	-0.82	-1.62	-73	to	350
10.	1,1,2-Trifluoroethane	432.	16.52	-16.32	-1.72	1.62	-73	to	350
11.	1-Chloro-1,1-difluoroethane	410.	14.43	-14.34	0.72	-2.15	-33	to	350
12.	2-Chloro-1,1-difluoroethane	490.	17.35	-17.02	-2.24	2.12	-33	to	350
13.	1,1-Dichloro-1-fluoroethane	473.	14.80	-16.00	-1.86	2.15	-33	to	350
14.	1,1,1-Trichloroethane	545.	17.00	-16.40	-2.74	2.37	-13	to	350
15.	1,1,2-Trichloroethane	605.	18.29	-17.47	-3.47	3.01	20	to	347
16.	1,1,2-Tribromoethane	705.	24.95	-23.66	-5.75	5.45	60	to	347
17.	1,1,1,2-Tetrafluoroethane	374.25	14.79	-14.11	0.57	0.48	-53	to	350
18.	1,1,2,2-Tetrafluoroethane	384.	15.60	-14.93	-1.55	0.45	-73	to	350
19.	2-Chloro-1,1,1-trifluoroethane	430.	16.25	-15.70	-1.97	1.00	-53	to	350
20.	1,2-Dichloro-1,1-difluoroethane	495.	17.00	-16.41	-2.51	1.97	-33	to	350
21.	1,1,1,2-Tetrachloroethane	610.	17.94	-17.31	-3.22	3.11	20	to	347
22.	1,1,2,2-Tetrachloroethane	635.	18.63	-17.89	-3.65	3.56	20	to	347
23.	Pentafluoroethane	339.4	15.00	-15.06	-1.62	0.15	-73	to	350
24.	Chloro-1,1,2,2-tetrafluoroethane	400.	15.56	-15.07	-1.79	0.90	-73	to	350
25.	Chloro-1,1,1,2-tetrafluoroethane	395.65	15.50	-15.33	-1.80	0.87	-73	to	350
26.	1,2-Dichloro-1,1,2-trifluoroethane	458.3	16.50	-16.03	-2.04	1.48	-53	to	350
27.	2,2-Dichloro-1,1,1-trifluoroethane	456.9	16.22	-15.33	-0.92	0.11	-73	to	350
28.	Pentachloroethane	670.	19.33	-18.31	-4.43	4.13	20	to	347
29.	Hexafluoroethane	293.	14.08	-13.00	-2.92	-1.96	-93	to	350
30.	Chloropentafluoroethane	353.15	14.96	-13.82	-1.70	-1.69	-73	to	350
31.	1,1-Dichlorotetrafluoroethane	418.7	16.07	-15.57	-1.91	1.18	-73	to	350
32.	1,2-Dichlorotetrafluoroethane	418.85	15.62	-14.34	0.18	0.68	-33	to	350
33.	1,2-Dibromotetrafluoroethane	488.	19.45	-18.29	-2.09	0.77	-33	to	350
34.	1,1,1-Trichlorotrifluoroethane	486.	16.86	-16.36	-2.33	1.89	-33	to	350
35.	1,1,2-Trichlorotrifluoroethane	487.35	16.70	-16.42	-2.38	1.90	-33	to	350
36.	Tetrachloro-1,2-difluoroethane	556.	17.83	-17.22	-2.77	2.29	20	to	347

TABLE 9.3 Ideal Gas Isobaric Specific Heat Capacity; Constants for Equation (6.1)

Compound		T_c	b_1	b_2	b_3	b_4	Range of applicability	
		K	kJ/kg K	kJ/kg K	kJ/kg K	kJ/kg K	°C	
1.	Chloroethane	460.	0.3635	0.7903	0.3680	-0.1992	-53	to 350
2.	Bromoethane	504.	0.2222	0.5426	0.2259	-0.1446	-33	to 330
3.	Iodoethane	563.	0.1683	0.4128	0.1958	-0.1388	-13	to 330
4.	1,1-Difluoroethane	386.55	0.3029	0.9703	0.0342	-0.0674	-33	to 350
5.	1,2-Difluoroethane	452.	0.5261	0.4958	0.5611	-0.2377	-53	to 350
6.	1,1-Dichloroethane	522.	0.2215	1.1116	-0.2443	-0.0171	-13	to 350
7.	1,2-Dichloroethane	563.	0.2430	1.1514	-0.2423	-0.0281	-13	to 350
8.	1,2-Dibromoethane	645.	0.1905	0.6164	-0.0669	-0.0671	20	to 347
9.	1,1,1-Trifluoroethane	346.25	0.1393	1.1419	-0.2663	0.0181	-73	to 350
10.	1,1,2-Trifluoroethane	432.	0.2739	1.0118	-0.0627	-0.0582	-73	to 350
11.	1-Chloro-1,1-difluoroethane	410.	0.1385	1.2047	-0.3794	0.0415	-33	to 350
12.	2-Chloro-1,1-difluoroethane	490.	0.2604	0.8412	0.0883	-0.1264	-33	to 350
13.	1,1-Dichloro-1-fluoroethane	473.	0.1631	1.3024	-0.5194	0.0764	-33	to 350
14.	1,1,1-Trichloroethane	545.	0.1677	1.2669	-0.6301	0.1229	-13	to 350
15.	1,1,2-Trichloroethane	605.	0.3605	0.3094	0.7806	-0.4953	20	to 347
16.	1,1,2-Tribromoethane	705.	0.1422	0.6837	-0.4029	0.0941	60	to 347
17.	1,1,1,2-Tetrafluoroethane	374.25	0.1485	1.0969	-0.2846	0.0194	-53	to 350
18.	1,1,2,2-Tetrafluoroethane	384.	0.2868	0.9474	-0.2433	0.0199	-73	to 350
19.	2-Chloro-1,1,1-trifluoroethane	430.	0.1522	1.0310	-0.2463	-0.0015	-53	to 350
20.	1,2-Dichloro-1,1-difluoroethane	495.	0.2448	0.9727	-0.2949	0.0124	-33	to 350
21.	1,1,1,2-Tetrachloroethane	610.	0.1625	1.2483	-0.7548	0.1786	20	to 347
22.	1,1,2,2-Tetrachloroethane	635.	0.1005	1.4241	-0.9231	0.2347	20	to 347
23.	Pentafluoroethane	339.4	0.1589	0.8873	-0.2016	0.0087	-73	to 350
24.	Chloro-1,1,2,2-tetrafluoroethane	400.	0.1474	1.0304	-0.3509	0.0397	-73	to 350
25.	Chloro-1,1,1,2-tetrafluoroethane	395.65	0.1499	0.9788	-0.3036	0.0270	-73	to 350
26.	1,2-Dichloro-1,1,2-trifluoroethane	458.3	0.1276	1.1429	-0.4921	0.0740	-53	to 350
27.	2,2-Dichloro-1,1,1-trifluoroethane	456.9	0.1368	1.0782	-0.4332	0.0592	-73	to 350
28.	Pentachloroethane	670.	0.0949	1.0327	-0.4537	0.0334	20	to 347
29.	Hexafluoroethane	293.	0.0916	0.9099	-0.2655	0.0277	-93	to 350
30.	Chloropentafluoroethane	353.15	0.1097	0.9988	-0.3701	0.0502	-73	to 350
31.	1,1-Dichlorotetrafluoroethane	418.7	0.1183	1.1053	-0.5115	0.0870	-73	to 350
32.	1,2-Dichlorotetrafluoroethane	418.85	0.0886	1.1865	-0.5645	0.0980	-33	to 350
33.	1,2-Dibromotetrafluoroethane	488.	0.1427	0.8574	-0.5602	0.1393	-33	to 350
34.	1,1,1-Trichlorotrifluoroethane	486.	0.1449	1.1517	-0.6369	0.1307	-33	to 350
35.	1,1,2-Trichlorotrifluoroethane	487.35	0.1254	1.2273	-0.7091	0.1522	-33	to 350
36.	Tetrachloro-1,2-difluoroethane	556.	0.1077	1.3772	-0.9627	0.2499	20	to 347

C₂H₅Cl CHLOROETHANE (ETHYL CHLORIDE, REFRIGERANT 160)

$M = 64.51$

$$\lambda^{(o)} \text{ and } \eta^{(o)} = b_1 + b_2 (1 - T_r) + b_3 (1 - T_r)^2 + b_4 (1 - T_r)^3,$$

$$c_p^{id} = b_1 + b_2 T_r + b_3 T_r^2 + b_4 T_r^3,$$

$$T_r = T/T_c, \quad T = \text{temperature (K)}, \quad T_c = \text{critical temperature} = 460. \text{ K } (= 186.85 \text{ } ^\circ\text{C})$$

	b_1	b_2	b_3	b_4	Equation
Thermal conductivity of dilute gas, $\lambda^{(o)}$ (mW/m K)	24.73	-43.28	14.75	4.80	(4.1)
Viscosity of dilute gas, $\eta^{(o)}$ ($\mu\text{N s/m}^2$)	14.65	-13.31	-0.80	-2.11	(5.1)
Specific heat capacity of ideal gas, c_p^{id} (kJ/kg K)	0.3635	0.7903	0.3680	-0.1992	(6.1)

T K	$\lambda^{(o)}$ mW/m K	$\eta^{(o)}$ $\mu\text{N s/m}^2$	c_p^{id} kJ/kg K	$Pr^{(o)}$ -	t $^\circ\text{C}$	$\lambda^{(o)}$ mW/m K	$\eta^{(o)}$ $\mu\text{N s/m}^2$	c_p^{id} kJ/kg K	$Pr^{(o)}$ -
220	6.8	7.2	0.804	0.84	-50	7.0	7.3	0.811	0.84
240	7.9	7.9	0.848	0.84	-30	8.1	8.0	0.855	0.84
260	9.1	8.5	0.892	0.84	-10	9.3	8.6	0.899	0.84
280	10.3	9.2	0.936	0.83	10	10.5	9.3	0.943	0.83
300	11.7	9.8	0.980	0.83	30	11.9	9.9	0.987	0.83
320	13.1	10.5	1.024	0.82	50	13.3	10.6	1.031	0.82
340	14.5	11.1	1.068	0.82	70	14.8	11.2	1.075	0.81
360	16.1	11.7	1.112	0.81	90	16.3	11.8	1.119	0.81
380	17.7	12.3	1.155	0.80	110	17.9	12.4	1.162	0.80
400	19.3	12.9	1.198	0.80	130	19.6	13.0	1.205	0.80
420	21.1	13.5	1.240	0.79	150	21.4	13.6	1.247	0.79
440	22.9	14.1	1.282	0.79	170	23.2	14.2	1.288	0.79
460	24.7	14.7	1.323	0.78	190	25.0	14.7	1.329	0.78
480	26.6	15.2	1.363	0.78	210	26.9	15.3	1.369	0.78
500	28.6	15.8	1.401	0.77	230	28.9	15.9	1.408	0.77
520	30.6	16.4	1.439	0.77	250	30.9	16.5	1.445	0.77
540	32.7	17.0	1.476	0.77	270	33.0	17.0	1.482	0.77
560	34.8	17.5	1.512	0.76	290	35.1	17.6	1.517	0.76
580	36.9	18.1	1.546	0.76	310	37.3	18.2	1.551	0.76
600	39.1	18.7	1.578	0.75	330	39.5	18.8	1.583	0.75
620	41.4	19.3	1.609	0.75	350	41.7	19.4	1.614	0.75

Data Sources (see Appendix A)

Thermal conductivity - A2.: 131, 421, 422, 491, 502, 532, 533, 541, 542, 605, 642, 661, 684, 686

Viscosity - A1.: 1, 2, 5

Specific heat capacity - A1.: 19

C₂H₅Br BROMOETHANE (ETHYL BROMIDE, REFRIGERANT 160B1)

$M = 108.97$

$$\lambda^{(o)} \text{ and } \eta^{(o)} = b_1 + b_2 (1 - T_r) + b_3 (1 - T_r)^2 + b_4 (1 - T_r)^3,$$

$$c_p^{id} = b_1 + b_2 T_r + b_3 T_r^2 + b_4 T_r^3,$$

$$T_r = T/T_c, \quad T = \text{temperature (K)}, \quad T_c = \text{critical temperature} = 504. \text{ K } (= 230.85 \text{ } ^\circ\text{C})$$

	b_1	b_2	b_3	b_4	Equation
Thermal conductivity of dilute gas, $\lambda^{(o)}$ (mW/m K)	23.07	-34.63	0	0	(4.1)
Viscosity of dilute gas, $\eta^{(o)}$ ($\mu\text{N s/m}^2$)	19.37	-19.20	-2.41	2.67	(5.1)
Specific heat capacity of ideal gas, c_p^{id} (kJ/kg K)	0.2222	0.5426	0.2259	-0.1446	(6.1)

T K	$\lambda^{(o)}$ mW/m K	$\eta^{(o)}$ $\mu\text{N s/m}^2$	c_p^{id} kJ/kg K	$Pr^{(o)}$ -	t $^\circ\text{C}$	$\lambda^{(o)}$ mW/m K	$\eta^{(o)}$ $\mu\text{N s/m}^2$	c_p^{id} kJ/kg K	$Pr^{(o)}$ -
240	4.9	9.0	0.516	0.95	-30	5.1	9.2	0.520	0.93
260	6.3	9.8	0.542	0.84	-10	6.5	9.9	0.547	0.83
280	7.7	10.6	0.569	0.78	10	7.9	10.7	0.573	0.78
300	9.1	11.4	0.595	0.75	30	9.3	11.5	0.599	0.74
320	10.4	12.2	0.621	0.72	50	10.6	12.3	0.625	0.72
340	11.8	13.0	0.647	0.71	70	12.0	13.1	0.651	0.71
360	13.2	13.7	0.672	0.70	90	13.4	13.9	0.676	0.70
380	14.5	14.5	0.698	0.70	110	14.8	14.7	0.702	0.70
400	15.9	15.3	0.723	0.70	130	16.1	15.5	0.727	0.70
420	17.3	16.1	0.748	0.70	150	17.5	16.2	0.751	0.70
440	18.7	16.9	0.772	0.70	170	18.9	17.0	0.776	0.70
460	20.0	17.7	0.796	0.70	190	20.3	17.8	0.799	0.70
480	21.4	18.5	0.819	0.71	210	21.6	18.6	0.823	0.71
500	22.8	19.2	0.842	0.71	230	23.0	19.3	0.845	0.71
520	24.2	20.0	0.864	0.71	250	24.4	20.1	0.867	0.71
540	25.5	20.7	0.885	0.72	270	25.8	20.8	0.888	0.72
560	26.9	21.5	0.906	0.72	290	27.1	21.6	0.909	0.72
580	28.3	22.2	0.925	0.73	310	28.5	22.3	0.928	0.73
600	29.7	22.9	0.944	0.73	330	29.9	23.0	0.947	0.73

Data Sources (see Appendix A)

Thermal conductivity - A2.: 131, 767

Specific heat capacity - A1.: 19