



ESDU 95019

Issued July 1995
With Amendment A
November 2006

Viscosity of liquids: Aliphatic ethers

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VISCOSITY OF LIQUIDS: ALIPHATIC ETHERS

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

Formula	Name	Alternative Name(s)
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C₂ to C₄ ETHERS

1. (CH ₃) ₂ O	Dimethyl ether	Methoxymethane Oxybismethane Methyl ether	7
2. CH ₃ OCH ₂ CH ₃	Methyl ethyl ether	Methoxyethane	8
3. CH ₃ O[CH ₂] ₂ CH ₃	Methyl propyl ether	1-Methoxypropane	9
4. CH ₃ OCH(CH ₃) ₂	Methyl isopropyl ether	2-Methoxypropane Methyl 1-methylethyl ether	10
5. (CH ₃ CH ₂) ₂ O	Diethyl ether	Ethoxyethane 1,1'-Oxybisethane Ethyl ether	11

C₅ ETHERS

6. CH ₃ O[CH ₂] ₃ CH ₃	Methyl butyl ether	1-Methoxybutane	13
7. CH ₃ OCH ₂ CH(CH ₃) ₂	Methyl isobutyl ether	1-Methoxy-2-methylpropane Methyl 2-methylpropyl ether	14

Formula	Name	Alternative Name(s)	
8. $\text{CH}_3\text{OC}(\text{CH}_3)_3$	Methyl <i>tert</i> -butyl ether	2-Methoxy-2-methylpropane Methyl 1,1-dimethylethyl ether MtBE	15
9. $\text{CH}_3\text{CH}_2\text{O}[\text{CH}_2]_2\text{CH}_3$	Ethyl propyl ether	1-Ethoxypropane	16
10. $\text{CH}_3\text{CH}_2\text{OCH}(\text{CH}_3)_2$	Ethyl isopropyl ether	2-Ethoxypropane Ethyl 1-methylethyl ether	17
C₆ ETHERS			
11. $\text{CH}_3\text{O}[\text{CH}_2]_4\text{CH}_3$	Methyl pentyl ether	1-Methoxypentane	18
12. $\text{CH}_3\text{O}[\text{CH}_2]_2\text{CH}(\text{CH}_3)_2$	Methyl isopentyl ether	1-Methoxy-3-methylbutane Methyl 3-methylbutyl ether 2-(2-Methoxyethyl)propane	19
13. $\text{CH}_3\text{CH}_2\text{O}[\text{CH}_2]_3\text{CH}_3$	Ethyl butyl ether	1-Ethoxybutane	20
14. $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}(\text{CH}_3)_2$	Ethyl isobutyl ether	1-Ethoxy-2-methylpropane Ethyl 2-methylpropyl ether	21
15. $\text{CH}_3\text{CH}_2\text{OC}(\text{CH}_3)_3$	Ethyl <i>tert</i> -butyl ether	2-Ethoxy-2-methylpropane Ethyl 1,1-dimethylethyl ether	22
16. $(\text{CH}_3[\text{CH}_2]_2)_2\text{O}$	Dipropyl ether	1,1'-Oxybispropane 1-Propoxypropane Propyl ether	23
17. $\text{CH}_3[\text{CH}_2]_2\text{OCH}(\text{CH}_3)_2$	Propyl isopropyl ether	2-Propoxypropane Propyl 1-methylethyl ether	24
18. $(\text{CH}_3)_2\text{CHOCH}(\text{CH}_3)_2$	Diisopropyl ether	2,2'-Oxybispropane Bis(1-methylethyl) ether 2-Isopropoxypropane Isopropyl ether	25
C₇ and C₈ ETHERS			
19. $\text{CH}_3[\text{CH}_2]_2\text{O}[\text{CH}_2]_3\text{CH}_3$	Propyl butyl ether	1-Propoxybutane	26
20. $(\text{CH}_3)_2\text{CHOC}(\text{CH}_3)_3$	Isopropyl <i>tert</i> -butyl ether	2-Isopropoxy-2-methylpropane 1-Methylethyl 1,1-dimethylethyl ether	27
21. $(\text{CH}_3[\text{CH}_2]_3)_2\text{O}$	Dibutyl ether	1,1'-Oxybisbutane 1-Butoxybutane Butyl ether	28
22. $(\text{CH}_3)_2\text{CHCH}_2\text{OCH}_2\text{CH}(\text{CH}_3)_2$	Diisobutyl ether	1,1'-Oxybis(2-methylpropane) Bis(2-methylpropyl) ether Isobutyl ether	29
23. $(\text{CH}_3)_3\text{COC}(\text{CH}_3)_3$	Ditert-butyl ether	2,2'-Oxybis(2-methylpropane) Bis(1,1-dimethylethyl) ether <i>tert</i> -Butyl ether	30

Formula	Name	Alternative Name(s)	
C₁₀ and C₁₂ ETHERS			
24. (CH ₃ [CH ₂] ₄) ₂ O	Dipentyl ether	1,1'-Oxybis(3-methylbutane) 1-Pentoxypentane Diamyl ether Pentyl ether Amyl ether	31
25. ((CH ₃) ₂ CH[CH ₂] ₂) ₂ O	Diisopentyl ether	1,1'-Oxybis(3-methylbutane) Bis(3-methylbutyl) ether Diisoamyl ether Isopentyl ether Isoamyl ether	32
26. (CH ₃ [CH ₂] ₅) ₂ O	Dihexyl ether	1,1'-Oxybishexane 1-Hexoxyhexane Hexyl ether	33
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VISCOSITY OF LIQUIDS: ALIPHATIC ETHERS

1. INTRODUCTION

This Item presents values for the viscosity at saturation pressure, in tabular form, for liquid aliphatic ethers. The range covered is from just above the melting temperature to about 0.9 times the critical temperature.

The values given are based on data which are believed to be the most reliable available and have been reviewed and suitably extended. In common with other Items, quantities are expressed in SI units and conversion factors to other units are provided in Section 3.

Section 4 gives the procedure used to obtain the values of viscosity presented and indicates the effect of pressure. Section 5 gives an explanation of the Tables and indicates the uncertainties in the values presented.

Appendix A provides a complete bibliography of data sources for this Item. Data sources for individual compounds are listed on the appropriate Data Sheet.

2. NOTATION AND UNITS

The SI unit of dynamic viscosity is the newton second per square metre (N s/m^2). The values presented in the tables are given in millinewton second per square metre (mN s/m^2), a submultiple which is convenient for the magnitudes considered and which is equal to the c.g.s. centipoise (cP).

A, B	dimensionless constants for each liquid in Equation (4.1)	-
C	constant for each liquid in Equation (4.2)	K
D	constant for each liquid in Equation (4.1)	mN s/m^2
p	pressure	N/m^2 (Pa)
T	kelvin temperature	K
t	Celsius temperature, $T - 273.15$	$^{\circ}\text{C}$
α	constant in Equation (4.3)	m^2/N
η	dynamic viscosity	mN s/m^2 (cP)
θ	dimensionless temperature dependent variable in Equation (4.2)	-

Subscripts

c	denotes value at the critical point
p	denotes value at pressure p
r	denotes reduced quantity, <i>e.g.</i> $T_r = T/T_c$.

3. CONVERSION FACTORS

$$\begin{aligned} 1 \text{ mN s/m}^2 &= 1 \text{ centipoise} \\ &= 145.04 \times 10^{-9} \text{ lbf s/in}^2 \\ &= 101.97 \times 10^{-6} \text{ kgf s/m}^2 \\ &= 10^{-3} \text{ kg/m s} \end{aligned}$$

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

4. LIQUID VISCOSITY

4.1 Viscosity at Saturation Pressure

The two equations most commonly used to describe variations of viscosity with temperature at saturation pressure are:

$$\ln \eta = A' + \frac{B'}{T},$$

and
$$\ln \eta = A'' + \frac{B''}{T - C''}.$$

Both of these can provide adequate representations of viscosity over limited ranges of temperature but are unsatisfactory over the full range. The first form often produces large deviations near the melting temperature or at higher viscosities, and neither is realistic for near-critical temperatures. Several equations are available which use molar volume as an independent variable but these are limited by the need for accurate volumetric data or an equation of state.

The following equation (Reference 1), which has been used for the present work has been found to give a good representation of the data from the melting temperature to $T_r = 0.9$:

$$\ln \frac{\eta}{D} = A(\theta - 1)^{1/3} + B(\theta - 1)^{4/3}, \quad (4.1)$$

where
$$\theta = \frac{T_c - C}{T - C}. \quad (4.2)$$

Relatively few reliable data are available at reduced temperatures greater than 0.9; however, the equation form is consistent with observed trends in that region and produces reasonable estimates close to the critical temperature.

Preliminary values for the constants A , B , C and D were derived from least square percentage deviation fits to the data sets which were considered to be the most accurate. It was found that satisfactory fits could be obtained with C set to $T_c/8$ and with A taken as constant and equal to 2.1. The constant C , which has the dimensions of temperature is much lower in value than the melting temperature. The constant D is in effect a pseudo-critical viscosity, which is produced by the equation at the critical point. Values for D were determined from viscosities close to the critical point where available. Values for B , and values for D not

obtained from critical region data were then obtained by fitting Equation (4.1) to viscosity data for individual compounds. Values for A , B , C and D are given in Table 7.1 and the critical temperatures for these substances have been taken from ESDU 95016 (Reference 2).

In view of the uncertainties in the experimental data, and the deviations between different data sets for certain compounds, it was found that different sets of B and D values gave equally acceptable data fits in some cases. Values for B and D were chosen so as to give a good correlation with corresponding values for other members of each chemical series, whilst maintaining an acceptable fit to the data for the compound under study. In this way a set of viscosity values was produced, which varied consistently within a given chemical series.

4.2 Effect of Pressure

No accurate general expression is available for estimating the effect of pressure on the viscosity of these liquids. However, the simple expression given for n -alkanes in ESDU 79027 (Reference 1) applies to these liquids under similar conditions and is reproduced here as an approximate guide.

The viscosity of liquids with high viscosity at saturation pressure increases more rapidly with pressure than that of liquids with a low viscosity at saturation pressure. In most cases, the viscosity increases by about 1 per cent for a pressure increase of 1 MPa (10 bar). Below the normal boiling point, the difference between values measured at atmospheric pressure and those at saturation is therefore very small.

For liquids from the melting temperature to about $0.75T_c$, the following relationship may be used as an approximate guide:

$$\ln \frac{\eta_p}{\eta} = \alpha p, \quad (4.3)$$

where η_p is the viscosity at pressure p , η is the viscosity at saturation pressure, and α is a pressure-viscosity coefficient. The average value for α is $1 \times 10^{-8} \text{ m}^2/\text{N}$ for pressures up to 50 MPa. For liquids in general, the higher the viscosity at saturation pressure, the higher the value of α .

5. EXPLANATION OF TABLES

The values of A , B , C and D to be used in Equations (4.1) and (4.2) are given in Table 7.1 together with the critical temperature and the range of applicability.

Values of the viscosity of individual compounds are given on separate sheets at 10 kelvin intervals with temperatures in K and °C. Extrapolated values are indicated in parenthesis. The sources of data used to derive the correlation are listed.

Experimental data from the most reliable sources have an estimated accuracy of $\pm 1\%$. However, such data are few in number and are generally restricted to temperatures close to ambient. No such data were available for any of the compounds in this Item. For many of these compounds, data from different sources differ widely, especially for low viscosities. Whilst it is considered that the procedure adopted here reduces the errors in the values presented to a minimum, it is recommended that the user allows for uncertainties as indicated in the tables. In general these are $\pm 5\%$ for temperature bands that include ambient and for compounds for which there are experimental data. Elsewhere it is recommended that the user allows for uncertainties of $\pm 10\%$ or $\pm 15\%$ as indicated in the tables.

6. REFERENCES

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

1. ESDU Viscosity of liquids: Aliphatic hydrocarbons Part 1. Alkanes. Data Item 79027, ESDU International plc, London, UK, 1979.
2. ESDU Vapour pressures and critical points of liquids: Aliphatic and aromatic ethers. Data Item 95016, ESDU International plc, London, UK, 1995.

7. TABLES

TABLE 7.1 Constants for Equations (4.1) and (4.2)

Compound		T_c K	A	B	C K	D mN s/m ²	Range of Applicability °C	
1.	Dimethyl ether	400.	2.1	0.250	50.00	0.0241	-130	to 80
2.	Methyl ethyl ether	437.85	2.1	0.307	54.73	0.0260	-140	to 120
3.	Methyl propyl ether	476.25	2.1	0.360	59.53	0.0279	-130	to 160
4.	Methyl isopropyl ether	464.48	2.1	0.360	58.06	0.0275	-130	to 150
5.	Diethyl ether	466.65	2.1	0.366	58.33	0.0271	-110	to 150
6.	Methyl butyl ether	512.75	2.1	0.412	64.10	0.0290	-110	to 190
7.	Methyl isobutyl ether	499.	2.1	0.396	62.37	0.0288	-110	to 180
8.	Methyl <i>tert</i> -butyl ether	497.1	2.1	0.463	62.14	0.0317	-110	to 180
9.	Ethyl propyl ether	500.4	2.1	0.414	62.55	0.0292	-110	to 180
10.	Ethyl isopropyl ether	486.	2.1	0.414	60.75	0.0289	-120	to 170
11.	Methyl pentyl ether	546.5	2.1	0.460	68.31	0.0300	-90	to 220
12.	Methyl isopentyl ether	532.	2.1	0.460	66.50	0.0300	-90	to 210
13.	Ethyl butyl ether	533.	2.1	0.460	66.62	0.0300	-90	to 210
14.	Ethyl isobutyl ether	522.	2.1	0.457	65.25	0.0291	-90	to 200
15.	Ethyl <i>tert</i> -butyl ether	514.	2.1	0.542	64.25	0.0321	-90	to 190
16.	Dipropyl ether	530.6	2.1	0.469	66.32	0.0302	-100	to 210
17.	Propyl isopropyl ether	517.	2.1	0.460	64.62	0.0300	-100	to 190
18.	Diisopropyl ether	500.32	2.1	0.460	62.54	0.0300	-110	to 180
19.	Propyl butyl ether	558.2	2.1	0.505	69.78	0.0311	-80	to 230
20.	Isopropyl <i>tert</i> -butyl ether	521.	2.1	0.645	65.12	0.0330	-90	to 200
21.	Dibutyl ether	583.	2.1	0.535	72.87	0.0322	-80	to 250
22.	Diisobutyl ether	561.	2.1	0.535	70.12	0.0322	-80	to 230
23.	Ditert-butyl ether	550.	2.1	0.804	68.75	0.0348	-60	to 220
24.	Dipentyl ether	628.	2.1	0.565	78.50	0.0343	-60	to 290
25.	Diisopentyl ether	616.	2.1	0.575	77.00	0.0345	-60	to 280
26.	Dihexyl ether	666.	2.1	0.590	83.25	0.0366	-30	to 320

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(CH₃)₂O DIMETHYL ETHER (METHOXYMETHANE, OXYBISMETHANE, METHYL ETHER)

$$\ln(\eta/D) = A(\theta - 1)^{1/3} + B(\theta - 1)^{4/3}$$

where $\theta = (T_c - C)/(T - C)$

η = viscosity at saturation pressure (mN s/m²)

$$T_c = 400. \text{ K}$$

$$A = 2.1, \quad B = 0.250, \quad C = 50.00, \quad D = 0.0241$$

T	η	Uncert.	T	η	Uncert.	t	η	Uncert.	t	η	Uncert.
K	mN s/m ²	in η %	K	mN s/m ²	in η %	°C	mN s/m ²	in η %	°C	mN s/m ²	in η %
140	(1.34)	15	250	(0.193)	15	-130	(1.20)	15	-20	(0.187)	15
150	(0.973)	15	260	(0.175)	15	-120	(0.890)	15	-10	(0.169)	15
160	(0.745)	15	270	(0.159)	15	-110	(0.691)	15	0	(0.154)	15
170	(0.593)	15	280	(0.145)	15	-100	(0.556)	15	10	(0.141)	15
180	(0.487)	15	290	(0.133)	10	-90	(0.460)	15	20	(0.129)	10
190	(0.410)	15	300	(0.122)	10	-80	(0.389)	15	30	(0.119)	10
200	(0.351)	15	310	(0.112)	10	-70	(0.335)	15	40	(0.109)	10
210	(0.305)	15	320	(0.103)	10	-60	(0.293)	15	50	(0.100)	10
220	(0.268)	15	330	(0.094)	10	-50	(0.258)	15	60	(0.092)	10
230	(0.238)	15	340	(0.086)	10	-40	(0.230)	15	70	(0.084)	10
240	(0.214)	15	350	(0.078)	10	-30	(0.207)	15	80	(0.076)	10

CH₃OCH₂CH₃ METHYL ETHYL ETHER (METHOXYETHANE)

$$\ln(\eta/D) = A(\theta - 1)^{1/3} + B(\theta - 1)^{4/3}$$

$$\text{where } \theta = (T_c - C)/(T - C)$$

η = viscosity at saturation pressure (mN s/m²)

$$T_c = 437.85 \text{ K}$$

$$A = 2.1, \quad B = 0.307, \quad C = 54.73, \quad D = 0.0260$$

T	η	Uncert.	T	η	Uncert.	t	η	Uncert.	t	η	Uncert.
K	mN s/m ²	in η %	K	mN s/m ²	in η %	°C	mN s/m ²	in η %	°C	mN s/m ²	in η %
130	(5.57)	15	270	(0.224)	15	-140	(4.60)	15	0	(0.217)	15
140	(3.20)	15	280	(0.203)	15	-130	(2.76)	15	10	(0.197)	15
150	(2.07)	15	290	(0.185)	15	-120	(1.84)	15	20	(0.180)	15
160	(1.45)	15	300	(0.170)	15	-110	(1.31)	15	30	(0.165)	15
170	(1.08)	15	310	(0.156)	15	-100	(0.993)	15	40	(0.152)	15
180	(0.840)	15	320	(0.143)	10	-90	(0.782)	15	50	(0.140)	10
190	(0.676)	15	330	(0.132)	10	-80	(0.635)	15	60	(0.129)	10
200	(0.559)	15	340	(0.122)	10	-70	(0.529)	15	70	(0.119)	10
210	(0.472)	15	350	(0.112)	10	-60	(0.449)	15	80	(0.109)	10
220	(0.405)	15	360	(0.103)	10	-50	(0.387)	15	90	(0.101)	10
230	(0.353)	15	370	(0.095)	10	-40	(0.339)	15	100	(0.093)	10
240	(0.311)	15	380	(0.087)	10	-30	(0.299)	15	110	(0.085)	10
250	(0.277)	15	390	(0.080)	10	-20	(0.267)	15	120	(0.077)	10
260	(0.248)	15				-10	(0.240)	15			