

Thermal conductivity of liquids: Glycol ethers

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THERMAL CONDUCTIVITY OF LIQUIDS: GLYCOL ETHERS

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

Formula	Name	Alternative Name(s)	
ETHYLENE GLYCOL MONOALKYL ETHERS			
1. $\text{CH}_3\text{O}[\text{CH}_2]_2\text{OH}$	Ethylene glycol monomethyl ether	2-Methoxyethanol 3-Oxabutan-1-ol Methyl glycol Methyl cellosolve	7
2. $\text{CH}_3\text{CH}_2\text{O}[\text{CH}_2]_2\text{OH}$	Ethylene glycol monoethyl ether	2-Ethoxyethanol 3-Oxapentan-1-ol Ethyl glycol Ethyl cellosolve Cellosolve	8
3. $\text{CH}_3[\text{CH}_2]_2\text{O}[\text{CH}_2]_2\text{OH}$	Ethylene glycol monopropyl ether	2-Propoxyethanol 3-Oxahexan-1-ol Propyl glycol Propyl cellosolve	10
4. $(\text{CH}_3)_2\text{CHO}[\text{CH}_2]_2\text{OH}$	Ethylene glycol monoisopropyl ether	2-Isopropoxyethanol 2-(1-Methylethoxy)ethanol 4-Methyl-3-oxapentan-1-ol Isopropyl glycol Isopropyl cellosolve	11

Formula	Name	Alternative Name(s)	
5. $\text{CH}_3[\text{CH}_2]_3\text{O}[\text{CH}_2]_2\text{OH}$	Ethylene glycol monobutyl ether	2-Butoxyethanol 3-Oxaheptan-1-ol Butyl glycol Butyl cellosolve	12
6. $(\text{CH}_3)_2\text{CHCH}_2\text{O}[\text{CH}_2]_2\text{OH}$	Ethylene glycol monoisobutyl ether	2-Isobutoxyethanol 2-(2-Methylpropoxy)ethanol 5-Methyl-3-oxahexan-1-ol Isobutyl glycol Isobutyl cellosolve	14
7. $\text{CH}_3[\text{CH}_2]_4\text{O}[\text{CH}_2]_2\text{OH}$	Ethylene glycol monopentyl ether	2-Pentoxyethanol 3-Oxaoctan-1-ol Pentyl glycol Pentyl cellosolve	15
8. $\text{CH}_3[\text{CH}_2]_5\text{O}[\text{CH}_2]_2\text{OH}$	Ethylene glycol monohexyl ether	2-Hexoxyethanol 3-Oxanonan-1-ol Hexyl glycol Hexyl cellosolve	16
DIETHYLENE GLYCOL ALKYL ETHERS			
9. $\text{CH}_3\text{O}[\text{CH}_2]_2\text{O}[\text{CH}_2]_2\text{OH}$	Diethylene glycol monomethyl ether	2-(2-Methoxyethoxy)ethanol 3,6-Dioxaheptan-1-ol Methyl diglycol Methyl digol Methyl carbitol	17
10. $\text{CH}_3\text{CH}_2\text{O}[\text{CH}_2]_2\text{O}[\text{CH}_2]_2\text{OH}$	Diethylene glycol monoethyl ether	2-(2-Ethoxyethoxy)ethanol 3,6-Dioxaoctan-1-ol Ethyl diglycol Ethyl digol Ethyl carbitol Carbitol	18
11. $\text{CH}_3[\text{CH}_2]_2\text{O}[\text{CH}_2]_2\text{O}[\text{CH}_2]_2\text{OH}$	Diethylene glycol monopropyl ether	2-(2-Propoxyethoxy)ethanol 3,6-Dioxanonan-1-ol Propyl diglycol Propyl digol Propyl carbitol	20
12. $\text{CH}_3[\text{CH}_2]_3\text{O}[\text{CH}_2]_2\text{O}[\text{CH}_2]_2\text{OH}$	Diethylene glycol monobutyl ether	2-(2-Butoxyethoxy)ethanol 3,6-Dioxadecan-1-ol Butyl diglycol Butyl digol Butyl carbitol	21
ETHYLENE GLYCOL DIALKYL ETHERS			
13. $\text{CH}_3\text{O}[\text{CH}_2]_2\text{OCH}_3$	Ethylene glycol dimethyl ether	1,2-Dimethoxyethane 2,5-Dioxaheptane Dimethyl glycol Dimethyl cellosolve Monoglyme	23

Formula	Name	Alternative Name(s)	
14. $\text{CH}_3\text{CH}_2\text{O}(\text{CH}_2)_2\text{OCH}_2\text{CH}_3$	Ethylene glycol diethyl ether	1,2-Diethoxyethane 3,6-Dioxaoctane Diethyl glycol Diethyl cellosolve Ethyl glyme	24
15. $\text{CH}_3(\text{CH}_2)_2\text{O}(\text{CH}_2)_2\text{O}(\text{CH}_2)_2\text{CH}_3$	Ethylene glycol dipropyl ether	1,2-Dipropoxyethane 4,7-Dioxadecane Dipropyl glycol Dipropyl cellosolve Propyl glyme	25
16. $\text{CH}_3(\text{CH}_2)_3\text{O}(\text{CH}_2)_2\text{O}(\text{CH}_2)_3\text{CH}_3$	Ethylene glycol dibutyl ether	1,2-Dibutoxyethane 5,8-Dioxadodecane Dibutyl glycol Dibutyl cellosolve Butyl glyme	26
DIETHYLENE GLYCOL DIALKYL ETHERS			
17. $\text{CH}_3\text{O}(\text{CH}_2)_2\text{O}(\text{CH}_2)_2\text{OCH}_3$	Diethylene glycol dimethyl ether	Bis(2-methoxyethyl) ether 2,5,8-Trioxanonane Dimethyl diglycol Dimethyl digol Dimethyl carbitol Diglyme	27
18. $\text{CH}_3\text{CH}_2\text{O}(\text{CH}_2)_2\text{O}(\text{CH}_2)_2\text{OCH}_2\text{CH}_3$	Diethylene glycol diethyl ether	Bis(2-ethoxyethyl) ether 3,6,9-Trioxaundecane Diethyl diglycol Diethyl digol Diethyl carbitol Ethyl diglyme	28
19. $\text{CH}_3(\text{CH}_2)_2\text{O}(\text{CH}_2)_2\text{O}(\text{CH}_2)_2\text{O}(\text{CH}_2)_2\text{CH}_3$	Diethylene glycol dipropyl ether	Bis(2-propoxyethyl) ether 4,7,10-Trioxatridecane Dipropyl diglycol Dipropyl digol Dipropyl carbitol Propyl diglyme	30
20. $\text{CH}_3(\text{CH}_2)_3\text{O}(\text{CH}_2)_2\text{O}(\text{CH}_2)_2\text{O}(\text{CH}_2)_3\text{CH}_3$	Diethylene glycol dibutyl ether	Bis(2-butoxyethyl) ether 5,8,11-Trioxapentadecane Dibutyl diglycol Dibutyl digol Dibutyl carbitol Butyl diglyme	31

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THERMAL CONDUCTIVITY OF LIQUIDS: GLYCOL ETHERS

1. INTRODUCTION

This Item presents values of thermal conductivity at saturation pressure, in tabular form, for liquid mono- and dialkyl ethylene and diethylene glycol ethers.

The data on which these recommended values of thermal conductivity are based are the most reliable available and the temperature range covered is from the melting temperature to approximately 0.9 of the critical temperature. Quantities are expressed in SI units and conversion factors to other units are provided in Section 3.

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

References to sources of supplementary information are given in Section 6. The data sources for each particular compound are listed on the appropriate data sheet.

2. NOTATION AND UNITS

The SI unit of thermal conductivity is the watt per metre kelvin (W/m K). A convenient submultiple SI unit for the range of thermal conductivity in this Item is the milliwatt per metre kelvin (mW/m K); hence that is the unit adopted here.

A	constant for each liquid in Equation (4.2)	mW/m K
A'	constant for each liquid in Equation (4.1)	mW/m K
B'	non-dimensional constant for each liquid in Equation (4.1)	–
B, C, D	non-dimensional constants for each liquid in Equation (4.2)	–
p	pressure	N/m ² (Pa)
T	kelvin temperature	K
t	Celsius temperature, $T - 273.15$	°C
λ	thermal conductivity	mW/m K

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

1 mW/m K	=	0.8598×10^{-3} kcal/m h °C*
	=	2.3885×10^{-6} cal/cm s °C*
	=	0.5778×10^{-3} Chu/ft h °C*
	=	0.5778×10^{-3} Btu/ft h °F*
	=	6.9335×10^{-3} Btu in/ft ² h °F*
10^5 N/m ²	=	1 bar
	=	14.5038 lbf/in ²
	=	1.0197 kgf/cm ²
	=	0.9869 atm
	=	750.062 mmHg.

* The values used for the calorie and British Thermal Unit are International Table values.

4. THERMAL CONDUCTIVITY

4.1 Thermal Conductivity at Saturation Pressure

In Reference 2 Riedel showed that the experimental data for the thermal conductivity of normal (that is unassociated) liquids along the saturation line could be represented by the equation:

$$\lambda = A'[1 + (20/3)(1 - T_r)^{2/3}].$$

For the liquids considered in this Item a better representation of the data is obtained, over a wide temperature range, from the modified equation which was used in some earlier ESDU Items:

$$\lambda = A'[1 + B'(1 - T_r)^{2/3}]. \quad (4.1)$$

The range of applicability of Equation (4.1) is limited for most compounds; recent data from several sources show that there may be marked deviations in the regions of the triple point and the critical point from extrapolations of Equation (4.1) fitted in the intermediate region.

For the liquids considered in this Item a good representation of the data* between the melting temperature and $T_r = 0.9$ is obtained from the equation:

$$\lambda = A[1 + B(1 - T_r)^{1/3} + C(1 - T_r)^{2/3} + D(1 - T_r)]. \quad (4.2)$$

Measurements of thermal conductivity have been made for relatively few liquids at $T_r > 0.9$ and so, because of the uncertain variation of thermal conductivity in the critical region, data are presented only for temperatures up to $T_r = 0.9$. The equation extrapolates in a physically realistic manner to within a few kelvin of the critical point.

The critical temperatures for these compounds have either been taken from ESDU 95004 (Reference 9) or

* Experimental data at temperatures below the normal boiling temperature, t_b , are often at 1 atm pressure. As indicated in Section 4.2 the difference between values of λ at 1 atm pressure and at saturation pressure below t_b is not significant.

estimated from correlations of ESDU values with chemical structure. In this Item, the critical temperatures should be regarded as correlating parameters only and should not be taken as a source of accurate values.

The derived values of A , B , C and D given in Table 7.1 are a correlated set of values giving the best fit to the experimental data, not only as individual compounds but also as members of their chemical series. This method of correlating data for a series of compounds has been described in References 5 and 6. For the monoalkyl glycol ethers in this Item, it was found that B , C and D could be held constant*, as was observed for other liquids exhibiting hydrogen bonding such as the alcohols. For the dialkyl glycol ethers in this Item, it was found that C and D are directly related to $B^\dagger$, as was observed for other non-hydrogen-bonded compounds such as the alkanes. Correlated values of the constants A , B , C and D were used to estimate constants for liquids for which no experimental data exist. Using these values with the values of T_c given in Table 7.1, values of λ in mW/m K have been calculated for each compound from Equation (4.2) and are presented in the data sheets.

4.2 Effect of Pressure

At temperatures up to the normal boiling point, the effect of pressure from the saturation pressure to $50 \times 10^5 \text{ N/m}^2$ (up to 50 atm) is to increase the thermal conductivity by approximately 1 per cent and, for most practical purposes, values at saturation pressure may be taken as equal to those at atmospheric pressure.

Reference 1 gives measurements of thermal conductivity for a number of liquids up to $12\,000 \times 10^5 \text{ N/m}^2$ ($\approx 12\,000 \text{ atm}$) at 30°C and 75°C . A generalised correlation of these results is given in Reference 3, but a knowledge of the critical pressure of the substance is required for its use.

For pressures up to $500 \times 10^5 \text{ N/m}^2$ ($\approx 500 \text{ atm}$) between the melting temperature and the normal boiling point a very approximate relationship:

$$\lambda_p/\lambda \approx 1 + 0.2p \times 10^{-8}, \quad (4.3)$$

may be used where λ_p is the thermal conductivity at pressure p and λ is the thermal conductivity at a pressure of 10^5 N/m^2 ($\approx 1 \text{ atm}$), both at the same temperature.

5. EXPLANATION OF TABLES

The constants of Equation (4.2) are given in Table 7.1 and on the data sheets. Values of the thermal conductivity are given in the data sheets at 10 kelvin intervals in K and $^\circ\text{C}$, from within 10 kelvin of the melting temperature, or an appropriate starting temperature where the melting temperature is unknown, to a temperature corresponding with $T_r \approx 0.9$.

The sources are given in the data sheets and extrapolated values are indicated in parentheses.

For uniformity and ease of interpolation the data are presented and can be read to more significant digits than is warranted by their estimated accuracy.

The experimental data from the most reliable individual sources have a repeatability of about ± 1 per cent although differences in technique used by different workers (and possibly also in the purity of samples) can increase the uncertainty in the absolute values to about ± 2 per cent. However, such reliable data are not available for all the compounds considered, nor over the whole temperature range covered. Although

* $B = 3.5$, $C = -8.1$, $D = 5.5$ for ethylene and diethylene glycol monoalkyl ethers.

† $C = 1 - 3B$ and $D = 3B$.

it is considered that the correlation procedures adopted keep the errors in the values presented to a minimum, the user should in general allow for an uncertainty of ± 5 per cent unless the value in the data sheets is truncated to a whole number. Where whole numbers are given the uncertainty increases to ± 10 per cent.

Some fluids have poor thermal stability coupled with a high critical temperature. Values have been tabulated for all fluids up to $T_r \approx 0.9$ but many of these fluids will decompose at elevated temperatures. As most compounds will decompose rapidly at temperatures above about 300 °C, uncertainties of greater than ± 10 per cent may occur for temperatures ≥ 573 K.

6. REFERENCES

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

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7. TABLES

TABLE 7.1 Constants for Equation (4.2)

Compound	T_c	A	B	C	D	Range of Applicability °C	
	K	mW/m K					
1. Ethylene glycol monomethyl ether	573.	122.0	3.5	-8.1	5.5	-90	to 250
2. Ethylene glycol monoethyl ether	584.	112.0	3.5	-8.1	5.5	-60	to 260
3. Ethylene glycol monopropyl ether	600.	106.5	3.5	-8.1	5.5	-50	to 270
4. Ethylene glycol monoisopropyl ether	587.	104.0	3.5	-8.1	5.5	-50	to 260
5. Ethylene glycol monobutyl ether	626.	103.0	3.5	-8.1	5.5	-40	to 300
6. Ethylene glycol monoisobutyl ether	606.	100.0	3.5	-8.1	5.5	-40	to 280
7. Ethylene glycol monopentyl ether	645.	100.0	3.5	-8.1	5.5	-50	to 320
8. Ethylene glycol monohexyl ether	670.	100.0	3.5	-8.1	5.5	-50	to 340
9. Diethylene glycol monomethyl ether	662.	117.0	3.5	-8.1	5.5	-50	to 330
10. Diethylene glycol monoethyl ether	668.	110.0	3.5	-8.1	5.5	-60	to 340
11. Diethylene glycol monopropyl ether	675.	104.0	3.5	-8.1	5.5	-50	to 340
12. Diethylene glycol monobutyl ether	689.	101.0	3.5	-8.1	5.5	-70	to 360
13. Ethylene glycol dimethyl ether	535.	80.0	1.00	-2.00	3.00	-60	to 220
14. Ethylene glycol diethyl ether	563.	73.8	0.85	-1.55	2.55	-80	to 240
15. Ethylene glycol dipropyl ether	598.	70.5	0.75	-1.25	2.25	-80	to 270
16. Ethylene glycol dibutyl ether	642.	67.0	0.70	-1.10	2.10	-70	to 310
17. Diethylene glycol dimethyl ether	610.	85.4	0.50	-0.50	1.50	-70	to 280
18. Diethylene glycol diethyl ether	635.	77.8	0.50	-0.50	1.50	-50	to 310
19. Diethylene glycol dipropyl ether	656.	73.7	0.50	-0.50	1.50	-50	to 330
20. Diethylene glycol dibutyl ether	685.	72.5	0.50	-0.50	1.50	-60	to 350

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