

Thermal conductivity of liquids: Carboxylic acids

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THE PREPARATION OF THIS DATA ITEM

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THERMAL CONDUCTIVITY OF LIQUIDS: CARBOXYLIC ACIDS

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

Formula	Name	Alternative Name(s)	
C₁ to C₁₀ ALKANOIC ACIDS			
1. HCOOH	Methanoic acid	Formic acid	7
2. CH ₃ COOH	Ethanoic acid	Acetic acid	9
3. CH ₃ CH ₂ COOH	Propanoic acid	Propionic acid	11
4. CH ₃ [CH ₂] ₂ COOH	Butanoic acid	Butyric acid	13
5. CH ₃ [CH ₂] ₃ COOH	Pentanoic acid	Valeric acid	15
6. CH ₃ [CH ₂] ₄ COOH	Hexanoic acid	Caproic acid	17
7. CH ₃ [CH ₂] ₅ COOH	Heptanoic acid	Oenanthic acid	18
8. CH ₃ [CH ₂] ₆ COOH	Octanoic acid	Caprylic acid	19
9. CH ₃ [CH ₂] ₇ COOH	Nonanoic acid	Pelargonic acid	20
10. CH ₃ [CH ₂] ₈ COOH	Decanoic acid	Capric acid	22
C₁₁ to C₂₀ ALKANOIC ACIDS			
11. CH ₃ [CH ₂] ₉ COOH	Undecanoic acid		23
12. CH ₃ [CH ₂] ₁₀ COOH	Dodecanoic acid	Lauric acid	24
13. CH ₃ [CH ₂] ₁₁ COOH	Tridecanoic acid		25
14. CH ₃ [CH ₂] ₁₂ COOH	Tetradecanoic acid	Myristic acid	26

Formula	Name	Alternative Name(s)	
15. $\text{CH}_3[\text{CH}_2]_{13}\text{COOH}$	Pentadecanoic acid		27
16. $\text{CH}_3[\text{CH}_2]_{14}\text{COOH}$	Hexadecanoic acid	Palmitic acid	28
17. $\text{CH}_3[\text{CH}_2]_{15}\text{COOH}$	Heptadecanoic acid	Margaric acid	30
18. $\text{CH}_3[\text{CH}_2]_{16}\text{COOH}$	Octadecanoic acid	Stearic acid	31
19. $\text{CH}_3[\text{CH}_2]_{17}\text{COOH}$	Nonadecanoic acid		33
20. $\text{CH}_3[\text{CH}_2]_{18}\text{COOH}$	Eicosanoic acid	Arachidic acid	34

C₂₁ to C₂₂ ALKANOIC ACIDS

21. $\text{CH}_3[\text{CH}_2]_{19}\text{COOH}$	Heneicosanoic acid		35
22. $\text{CH}_3[\text{CH}_2]_{20}\text{COOH}$	Docosanoic acid	Behenic acid	36

METHYLALKANOIC ACIDS

23. $(\text{CH}_3)_2\text{CHCOOH}$	2-Methylpropanoic acid	Isobutyric acid 2-Methylpropionic acid	37
24. $(\text{CH}_3)_2\text{CHCH}_2\text{COOH}$	3-Methylbutanoic acid	Isovaleric acid 3-Methylbutyric acid	38
25. $(\text{CH}_3)_2\text{CH}[\text{CH}_2]_2\text{COOH}$	4-Methylpentanoic acid	4-Methylvaleric acid Isocaproic acid Isohexanoic acid	39

ALKENOIC ACIDS

26. $\text{H}_2\text{C}=\text{CHCOOH}$	Propenoic acid	Acrylic acid	40
27. <i>cis</i> -(CH_3)HC=CHCOOH	<i>cis</i> -But-2-enoic acid	Isocrotonic acid	41
28. <i>trans</i> -(CH_3)HC=CHCOOH	<i>trans</i> -But-2-enoic acid	Crotonic acid	42
29. <i>cis</i> - $\text{CH}_3[\text{CH}_2]_7\text{HC}=\text{CH}[\text{CH}_2]_7\text{COOH}$	<i>cis</i> -Octadec-9-enoic acid	Oleic acid	43
30. <i>trans</i> - $\text{CH}_3[\text{CH}_2]_7\text{HC}=\text{CH}[\text{CH}_2]_7\text{COOH}$	<i>trans</i> -Octadec-9-enoic acid	Elaidic acid	45

ALKYLALKENOIC ACIDS

31. $\text{H}_2\text{C}=\text{C}(\text{CH}_3)\text{COOH}$	2-Methylpropenoic acid	Methacrylic acid	46
32. <i>cis</i> -(CH_3)HC=C(CH_3)COOH	<i>cis</i> -2-Methylbut-2-enoic acid	Angelic acid	47
33. <i>trans</i> -(CH_3)HC=C(CH_3)COOH	<i>trans</i> -2-Methylbut-2-enoic acid	Tiglic acid	48
34. $\text{H}_2\text{C}=\text{C}(\text{CH}_2\text{CH}_3)\text{COOH}$	2-Ethylpropenoic acid	Ethacrylic acid Ethylacrylic acid	49

ALAKADIENOIC and ALKATRIENOIC ACIDS

35. $\text{CH}_3[\text{CH}_2]_3((\text{CH}_2)\text{HC}=\text{CH})_2[\text{CH}_2]_7\text{COOH}$	Octadeca-9,12-dienoic acid	Linoleic acid	50
36. $\text{CH}_3((\text{CH}_2)\text{HC}=\text{CH})_3[\text{CH}_2]_7\text{COOH}$	Octadeca-9,12,15-trienoic acid	Linolenic acid	51

THERMAL CONDUCTIVITY OF LIQUIDS: CARBOXYLIC ACIDS

1. INTRODUCTION

This Item presents values of thermal conductivity at saturation pressure, in tabular form, for straight and branched chain liquid aliphatic carboxylic acids.

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

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

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

* 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.

* 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.

The critical temperatures for these compounds have either been taken from ESDU 80029 (Reference 6) or estimated. 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 series of compounds has been described in References 5 and 7. For the carboxylic acids in this Item, it was found that B and C could be held constant*, as was observed for other liquids exhibiting hydrogen bonding such as the alcohols and amines. 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 $T_f \approx 0.9$.

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 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 sheet is

* $B = 3.5$ and $C = -6.5$.

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		
		K	mW/m K				°C		
1.	Methanoic acid	579.	126.9	3.5	-6.5	4.70	10	to	260
2.	Ethanoic acid	592.7	76.0	3.5	-6.5	4.80	20	to	270
3.	Propanoic acid	611.	68.7	3.5	-6.5	4.90	-20	to	280
4.	Butanoic acid	631.	64.2	3.5	-6.5	5.05	-10	to	300
5.	Pentanoic acid	649.	61.1	3.5	-6.5	5.15	-40	to	320
6.	Hexanoic acid	665.	59.1	3.5	-6.5	5.25	0	to	330
7.	Heptanoic acid	680.	57.5	3.5	-6.5	5.35	-10	to	350
8.	Octanoic acid	695.	56.0	3.5	-6.5	5.50	20	to	360
9.	Nonanoic acid	709.	55.0	3.5	-6.5	5.60	10	to	370
10.	Decanoic acid	722.	54.5	3.5	-6.5	5.70	30	to	380
11.	Undecanoic acid	750.	53.6	3.5	-6.5	5.80	30	to	410
12.	Dodecanoic acid	748.	53.1	3.5	-6.5	5.90	40	to	410
13.	Tridecanoic acid	773.	52.7	3.5	-6.5	6.00	40	to	430
14.	Tetradecanoic acid	770.	51.8	3.5	-6.5	6.15	50	to	430
15.	Pentadecanoic acid	794.	51.4	3.5	-6.5	6.25	50	to	450
16.	Hexadecanoic acid	791.	51.8	3.5	-6.5	6.35	60	to	450
17.	Heptadecanoic acid	813.	50.6	3.5	-6.5	6.45	60	to	470
18.	Octadecanoic acid	810.	49.8	3.5	-6.5	6.55	70	to	460
19.	Nonadecanoic acid	831.	49.4	3.5	-6.5	6.65	70	to	480
20.	Eicosanoic acid	839.	48.4	3.5	-6.5	6.80	70	to	490
21.	Heneicosanoic acid	847.	47.7	3.5	-6.5	6.90	70	to	500
22.	Docosanoic acid	855.	47.2	3.5	-6.5	7.00	80	to	500
23.	2-Methylpropanoic acid	620.	55.5	3.5	-6.5	5.05	-50	to	290
24.	3-Methylbutanoic acid	639.	53.6	3.5	-6.5	5.15	-40	to	310
25.	4-Methylpentanoic acid	655.	51.6	3.5	-6.5	5.25	-30	to	320
26.	Propenoic acid	615.	73.1	3.5	-6.5	4.90	10	to	290
27.	<i>cis</i> -But-2-enoic acid	650.	66.7	3.5	-6.5	5.05	10	to	320
28.	<i>trans</i> -But-2-enoic acid	670.	66.7	3.5	-6.5	5.05	70	to	340
29.	<i>cis</i> -Octadec-9-enoic acid	797.	47.6	3.5	-6.5	6.55	10	to	450
30.	<i>trans</i> -Octadec-9-enoic acid	799.	47.6	3.5	-6.5	6.55	40	to	450

TABLE 7.1 Constants for Equation (4.2) (Continued)

Compound		T_c K	A mW/m K	B	C	D	Range of Applicability °C		
31.	2-Methylpropenoic acid	638.	62.8	3.5	-6.5	5.05	10	to	310
32.	<i>cis</i> -2-Methylbut-2-enoic acid	668.	59.7	3.5	-6.5	5.15	40	to	340
33.	<i>trans</i> -2-Methylbut-2-enoic acid	688.	59.7	3.5	-6.5	5.15	60	to	350
34.	2-Ethylpropenoic acid	656.	59.7	3.5	-6.5	5.15	30	to	330
35.	Octadeca-9,12-dienoic acid	817.	47.5	3.5	-6.5	6.55	-10	to	470
36.	Octadeca-9,12,15-trienoic acid	812.	47.5	3.5	-6.5	6.55	-10	to	470

HCOOH METHANOIC ACID (FORMIC ACID)

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

where

λ = thermal conductivity at saturation pressure (mW/m K)

$$T_r = T/T_c \quad T = \text{temperature (K)}$$

$$T_c = 579. \text{ K}$$

$$A = 126.9, \quad B = 3.5, \quad C = -6.5, \quad D = 4.70$$

T K	λ mW/m K	T K	λ mW/m K
280	(260.)	410	233.
290	257.9	420	231.
300	255.5	430	229.
310	253.2	440	(228.)
320	250.9	450	(226.)
330	248.7	460	(224.)
340	246.5	470	(223.)
350	244.4	480	(221.)
360	242.3	490	(220.)
370	240.3	500	(218.)
380	238.	510	(217.)
390	236.	520	(215.)
400	234.	530	(213.)

t °C	λ mW/m K	t °C	λ mW/m K
10	259.5	140	232.
20	257.1	150	230.
30	254.8	160	229.
40	252.5	170	(227.)
50	250.2	180	(225.)
60	248.0	190	(224.)
70	245.8	200	(222.)
80	243.7	210	(221.)
90	241.6	220	(219.)
100	239.6	230	(218.)
110	238.	240	(216.)
120	236.	250	(215.)
130	234.	260	(213.)

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CH₃COOH ETHANOIC ACID (ACETIC ACID)

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

where

λ = thermal conductivity at saturation pressure (mW/m K)

$$T_r = T/T_c \quad T = \text{temperature (K)}$$

$$T_c = 592.7 \text{ K}$$

$$A = 76.0, \quad B = 3.5, \quad C = -6.5, \quad D = 4.80$$

T K	λ mW/m K	T K	λ mW/m K
290	159.3	420	(142.)
300	157.8	430	(140.)
310	156.3	440	(139.)
320	154.8	450	(138.)
330	153.3	460	(137.)
340	151.9	470	(136.)
350	(150.5)	480	(135.)
360	(149.1)	490	(134.)
370	(147.8)	500	(133.)
380	(146.5)	510	(132.)
390	(145.2)	520	(131.)
400	(144.)	530	(130.)
410	(143.)	540	(129.)

t °C	λ mW/m K	t °C	λ mW/m K
20	158.8	150	(141.)
30	157.3	160	(140.)
40	155.8	170	(139.)
50	154.3	180	(138.)
60	152.9	190	(137.)
70	151.5	200	(136.)
80	(150.1)	210	(135.)
90	(148.7)	220	(134.)
100	(147.4)	230	(133.)
110	(146.1)	240	(132.)
120	(144.8)	250	(131.)
130	(144.)	260	(130.)
140	(142.)	270	(128.)

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CH₃CH₂COOH PROPANOIC ACID (PROPIONIC ACID)

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

where

λ = thermal conductivity at saturation pressure (mW/m K)

$$T_r = T/T_c \quad T = \text{temperature (K)}$$

$$T_c = 611. \text{ K}$$

$$A = 68.7, \quad B = 3.5, \quad C = -6.5, \quad D = 4.90$$

T K	λ mW/m K	T K	λ mW/m K	t °C	λ mW/m K	t °C	λ mW/m K
250	(155.)	410	132.6	-20	(154.)	140	132.2
260	(153.)	420	131.4	-10	(153.)	150	131.1
270	(152.)	430	130.3	0	151.4	160	129.9
280	150.3	440	(129.1)	10	149.9	170	(128.8)
290	148.8	450	(128.0)	20	148.4	180	(127.7)
300	147.4	460	(126.9)	30	146.9	190	(126.6)
310	145.9	470	(125.9)	40	145.4	200	(125.5)
320	144.5	480	(125.)	50	144.0	210	(124.)
330	143.1	490	(124.)	60	142.6	220	(123.)
340	141.7	500	(123.)	70	141.2	230	(122.)
350	140.3	510	(122.)	80	139.9	240	(121.)
360	139.0	520	(121.)	90	138.5	250	(121.)
370	137.6	530	(120.)	100	137.2	260	(120.)
380	136.4	540	(119.)	110	136.0	270	(118.)
390	135.1	550	(118.)	120	134.7	280	(117.)
400	133.8			130	133.5		

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CH₃[CH₂]₂COOH BUTANOIC ACID (BUTYRIC ACID)

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

where

λ = thermal conductivity at saturation pressure (mW/m K)

$$T_r = T/T_c \quad T = \text{temperature (K)}$$

$$T_c = 631. \text{ K}$$

$$A = 64.2, \quad B = 3.5, \quad C = -6.5, \quad D = 5.05$$

T K	λ mW/m K	T K	λ mW/m K
260	(150.)	420	127.5
270	(149.)	430	126.3
280	147.1	440	125.1
290	145.6	450	(123.9)
300	144.1	460	(122.7)
310	142.6	470	(121.6)
320	141.1	480	(120.)
330	139.7	490	(119.)
340	138.2	500	(118.)
350	136.8	510	(117.)
360	135.4	520	(116.)
370	134.1	530	(115.)
380	132.7	540	(114.)
390	131.4	550	(113.)
400	130.1	560	(112.)
410	128.8	570	(111.)

t °C	λ mW/m K	t °C	λ mW/m K
-10	(150.)	150	127.1
0	148.1	160	125.9
10	146.6	170	124.7
20	145.1	180	(123.5)
30	143.6	190	(122.4)
40	142.1	200	(121.2)
50	140.6	210	(120.)
60	139.2	220	(119.)
70	137.8	230	(118.)
80	136.4	240	(117.)
90	135.0	250	(116.)
100	133.6	260	(115.)
110	132.3	270	(114.)
120	131.0	280	(113.)
130	129.7	290	(112.)
140	128.4	300	(110.)

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