



Viscosity of liquids: Carboxylic acids

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VISCOSITY 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	8
3. CH ₃ CH ₂ COOH	Propanoic acid	Propionic acid	10
4. CH ₃ [CH ₂] ₂ COOH	Butanoic acid	Butyric acid	12
5. CH ₃ [CH ₂] ₃ COOH	Pentanoic acid	Valeric acid	14
6. CH ₃ [CH ₂] ₄ COOH	Hexanoic acid	Caproic acid	16
7. CH ₃ [CH ₂] ₅ COOH	Heptanoic acid	Oenanthic acid	18
8. CH ₃ [CH ₂] ₆ COOH	Octanoic acid	Caprylic acid	20
9. CH ₃ [CH ₂] ₇ COOH	Nonanoic acid	Pelargonic acid	22
10. CH ₃ [CH ₂] ₈ COOH	Decanoic acid	Capric acid	24

Formula	Name	Alternative Name(s)
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C₁₁ to C₂₀ ALKANOIC ACIDS

11.	CH ₃ [CH ₂] ₉ COOH	Undecanoic acid	26
12.	CH ₃ [CH ₂] ₁₀ COOH	Dodecanoic acid	Lauric acid 27
13.	CH ₃ [CH ₂] ₁₁ COOH	Tridecanoic acid	29
14.	CH ₃ [CH ₂] ₁₂ COOH	Tetradecanoic acid	Myristic acid 30
15.	CH ₃ [CH ₂] ₁₃ COOH	Pentadecanoic acid	32
16.	CH ₃ [CH ₂] ₁₄ COOH	Hexadecanoic acid	Palmitic acid 33
17.	CH ₃ [CH ₂] ₁₅ COOH	Heptadecanoic acid	Margaric acid 35
18.	CH ₃ [CH ₂] ₁₆ COOH	Octadecanoic acid	Stearic acid 36
19.	CH ₃ [CH ₂] ₁₇ COOH	Nonadecanoic acid	38
20.	CH ₃ [CH ₂] ₁₈ COOH	Eicosanoic acid	Arachidic acid 39

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VISCOSITY OF LIQUIDS: CARBOXYLIC ACIDS

1. INTRODUCTION

This Item presents values for the viscosity at saturation pressure, in tabular form, for liquid alkanoic acids. 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. The critical temperatures for these substances have been taken from ESDU 80029, 93017 (References 2 and 3), except for odd-numbered acids from C_{11} and higher. For these acids, pseudo- T_c values were obtained from the smooth curve of T_c versus carbon number for acids up to C_{10} and higher, even-numbered acids.

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 uncertainty bands of $\pm 10\%$ are more typical but these may amount to $\pm 15\%$ or even $\pm 20\%$ in some cases.

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 carboxylic acids and anhydrides. Data Item 80029, ESDU International plc, London, UK, 1980.
3. ESDU Thermal conductivity of liquids: Carboxylic acids. Data Item 93017, ESDU International plc, London, UK, 1993.

7. TABLES

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

Compound	T_c	A	B	C	D	Range of Applicability °C
	K					
1. Methanoic acid	579.	2.1	0.951	72.37	0.0473	10 to 240
2. Ethanoic acid	592.7	2.1	0.631	74.08	0.0458	20 to 250
3. Propanoic acid	611.	2.1	0.503	76.37	0.0439	-20 to 270
4. Butanoic acid	631.	2.1	0.621	78.87	0.0439	-10 to 290
5. Pentanoic acid	649.	2.1	0.713	81.12	0.0447	-40 to 310
6. Hexanoic acid	665.	2.1	0.771	83.12	0.0480	0 to 320
7. Heptanoic acid	680.	2.1	0.817	85.00	0.0505	-10 to 340
8. Octanoic acid	695.	2.1	0.864	86.87	0.0525	20 to 350
9. Nonanoic acid	709.	2.1	0.910	88.62	0.0541	10 to 360
10. Decanoic acid	722.	2.1	0.947	90.25	0.0549	30 to 370
11. Undecanoic acid	735.*	2.1	0.972	91.87	0.0556	30 to 400
12. Dodecanoic acid	748.	2.1	0.985	93.50	0.0560	40 to 400
13. Tridecanoic acid	760.*	2.1	1.012	95.00	0.0564	40 to 420
14. Tetradecanoic acid	770.	2.1	1.025	96.25	0.0565	50 to 420
15. Pentadecanoic acid	780.*	2.1	1.040	97.50	0.0569	50 to 440
16. Hexadecanoic acid	791.	2.1	1.054	98.87	0.0570	60 to 440
17. Heptadecanoic acid	800.*	2.1	1.059	100.00	0.0570	60 to 460
18. Octadecanoic acid	810.	2.1	1.063	101.25	0.0570	70 to 460
19. Nonadecanoic acid	825.*	2.1	1.067	103.12	0.0570	70 to 480
20. Eicosanoic acid	839.	2.1	1.070	104.87	0.0570	70 to 480

* Pseudo- T_c values, obtained from the smooth curve of T_c versus carbon number for acids up to C_{10} and higher even-numbered acids, are tabulated here.

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HCOOH METHANOIC ACID (FORMIC ACID)

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

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

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

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

$$A = 2.1, \quad B = 0.951, \quad C = 72.37, \quad D = 0.0473$$

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
		%			%			%			%
280	2.38	5	400	(0.403)	5	10	2.21	5	130	(0.390)	5
290	1.91	5	410	(0.366)	5	20	1.79	5	140	(0.355)	5
300	1.56	5	420	(0.334)	5	30	1.47	5	150	(0.324)	5
310	1.30	5	430	(0.305)	10	40	1.23	5	160	(0.297)	10
320	1.09	5	440	(0.280)	10	50	1.04	5	170	(0.273)	10
330	0.936	5	450	(0.258)	10	60	0.893	5	180	(0.251)	10
340	0.810	5	460	(0.237)	10	70	0.775	5	190	(0.232)	10
350	0.707	5	470	(0.219)	10	80	0.679	5	200	(0.214)	10
360	0.623	5	480	(0.203)	10	90	0.600	5	210	(0.198)	10
370	0.554	5	490	(0.187)	10	100	0.534	5	220	(0.183)	10
380	(0.495)	5	500	(0.173)	10	110	(0.479)	5	230	(0.169)	10
390	(0.445)	5	510	(0.159)	10	120	(0.431)	5	240	(0.155)	10

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CH₃COOH ETHANOIC ACID (ACETIC ACID)

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

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

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

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

$$A = 2.1, \quad B = 0.631, \quad C = 74.08, \quad D = 0.0458$$

T K	η mN s/m ²	Uncert. in η %	T K	η mN s/m ²	Uncert. in η %	t °C	η mN s/m ²	Uncert. in η %	t °C	η mN s/m ²	Uncert. in η %
290	1.29	5	410	(0.336)	5	20	1.23	5	140	(0.328)	5
300	1.10	5	420	(0.311)	5	30	1.05	5	150	(0.304)	5
310	0.951	5	430	(0.288)	10	40	0.911	5	160	(0.282)	10
320	0.831	5	440	(0.268)	10	50	0.797	5	170	(0.262)	10
330	0.732	5	450	(0.249)	10	60	0.705	5	180	(0.244)	10
340	0.651	5	460	(0.232)	10	70	0.628	5	190	(0.227)	10
350	0.583	5	470	(0.217)	10	80	0.564	5	200	(0.212)	10
360	0.526	5	480	(0.202)	10	90	0.509	5	210	(0.198)	10
370	0.476	5	490	(0.189)	10	100	0.462	5	220	(0.185)	10
380	0.434	5	500	(0.176)	10	110	0.422	5	230	(0.172)	10
390	(0.397)	5	510	(0.164)	10	120	(0.387)	5	240	(0.160)	10
400	(0.365)	5	520	(0.153)	10	130	(0.356)	5	250	(0.149)	10

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CH₃CH₂COOH PROPANOIC ACID (PROPIONIC ACID)

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

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

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

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

$$A = 2.1, \quad B = 0.503, \quad C = 76.37, \quad D = 0.0439$$

T K	η mN s/m ²	Uncert. in η %	T K	η mN s/m ²	Uncert. in η %	t °C	η mN s/m ²	Uncert. in η %	t °C	η mN s/m ²	Uncert. in η %
250	(2.43)	10	400	0.360	5	-20	(2.27)	10	130	0.352	5
260	(1.96)	5	410	0.334	5	-10	(1.84)	5	140	0.326	5
270	(1.62)	5	420	(0.311)	5	0	(1.53)	5	150	(0.304)	5
280	1.36	5	430	(0.289)	5	10	1.29	5	160	(0.283)	5
290	1.16	5	440	(0.270)	5	20	1.10	5	170	(0.264)	5
300	0.999	5	450	(0.253)	10	30	0.956	5	180	(0.247)	10
310	0.873	5	460	(0.237)	10	40	0.839	5	190	(0.232)	10
320	0.771	5	470	(0.222)	10	50	0.743	5	200	(0.217)	10
330	0.686	5	480	(0.208)	10	60	0.663	5	210	(0.204)	10
340	0.616	5	490	(0.195)	10	70	0.596	5	220	(0.191)	10
350	0.556	5	500	(0.183)	10	80	0.539	5	230	(0.179)	10
360	0.505	5	510	(0.172)	10	90	0.491	5	240	(0.168)	10
370	0.462	5	520	(0.161)	10	100	0.449	5	250	(0.158)	10
380	0.423	5	530	(0.151)	15	110	0.412	5	260	(0.147)	15
390	0.390	5	540	(0.141)	15	120	0.380	5	270	(0.138)	15

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