Standard Viscosity-Temperature Charts for Liquid Petroleum Products[1]

This standard is issued under the fixed designation D 341; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 The kinematic viscosity-temperature charts (see Figs. 1 and 2) covered by this standard are a convenient means to ascertain the kinematic viscosity of a petroleum oil or liquid hydrocarbon at any temperature within a limited range, provided that the kinematic viscosities at two temperatures are known.

1.2 The charts are designed to permit petroleum oil kinematic viscosity-temperature data to plot as a straight line. The charts here presented provide a significant improvement in linearity over the charts previously available under Method D 341 – 43. This increases the reliability of extrapolation to higher temperatures.

2. Referenced Documents

2.1 *ASTM Standards:*

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)[2]

2.2 *ASTM Adjuncts:*

Adjunct D 341, Viscosity-Temperature Charts 1–7[3]

3. Technical Hazard

3.1 **Caution**—The charts should be used only in that range in which the hydrocarbon or petroleum fluids are homogeneous liquids. The suggested range is thus between the cloud point at low temperatures and the initial boiling point at higher temperatures. The charts provide improved linearity in both low kinematic viscosity and at temperatures up to 340°C (approximately 650°F) or higher. Some high-boiling point materials can show a small deviation from a straight line as low as 280°C (approximately 550°F), depending on the individual sample or accuracy of the data. Reliable data can be usefully plotted in the high temperature region even if it does exhibit some curvature. Extrapolations into such regions from lower temperatures will lack accuracy, however. Experimental data taken below the cloud point or temperature of crystal growth will generally not be of reliable repeatability for interpolation or extrapolation on the charts. It should also be emphasized that fluids other than hydrocarbons will usually not plot as a straight line on these charts.

[1] These charts are under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and are the direct responsibility of Subcommittee D02.07 on Flow Properties.

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[2] *Annual Book of ASTM Standards*, Vol 05.01.

[3] Available from ASTM International Headquarters. Order Adjunct No. ADJD0341CS.

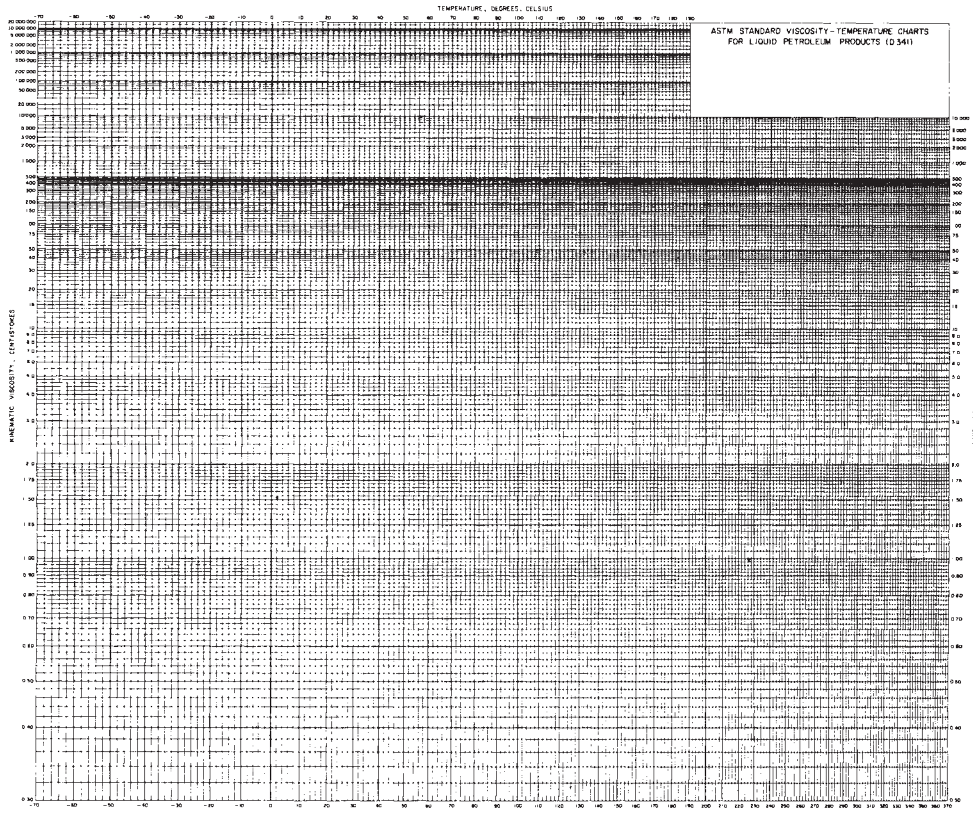

FIG. 1 Facsimile of Kinematic Viscosity-Temperature Chart I High Range (Temperature in degrees Celsius)

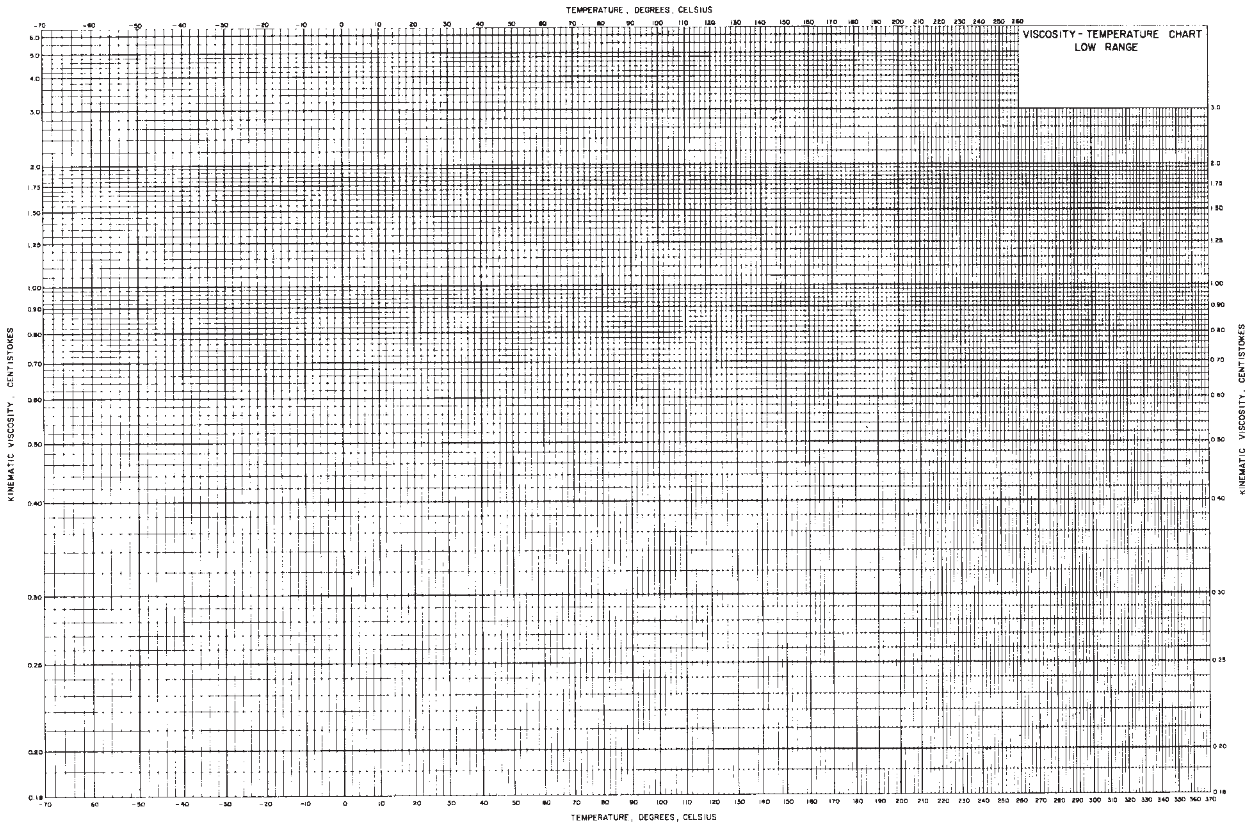

FIG. 2 Facsimile of Kinematic Viscosity-Temperature Chart II Low Range (Temperature in degrees Celsius)

4. Description

4.1 The charts are designed to permit kinematic viscosity-temperature data for a petroleum oil or fraction, and hydrocarbons in general, to plot as a straight line over a wide range. Seven charts are available as follows:[3]

Chart I—Kinematic Viscosity, High Range:
Kinematic Viscosity: 0.3 to 20 000 000 cSt
Temperature: − 70 to + 370°C
Size: 680 by 820 mm (26.75 by 32.25 in.)
Pad of 50
ADJD034101

Chart II— Kinematic Viscosity, Low Range:
Kinematic Viscosity: 0.18 to 6.5 cSt
Temperature: − 70 to + 370°C
Size: 520 by 820 mm (20.5 by 32.25 in.)
Pad of 50
ADJD034102

Chart III—Kinematic Viscosity, High Range:
Kinematic Viscosity: 0.3 to 20 000 000 cSt
Temperature: − 70 to + 370°C
Size: 217 by 280 mm (8.5 by 11.0 in.)
Pad of 50
ADJD034103

Chart IV—Kinematic Viscosity, Low Range:
Kinematic Viscosity: 0.18 to 6.5 cSt
Temperature: − 70 to + 370°C
Size: 217 by 280 mm (8.5 to 11.0 in.)
Pad of 50
ADJD034104

Chart V—Kinematic Viscosity, High Range:
Kinematic Viscosity: 0.3 to 20 000 000 cSt
Temperature: − 100 to + 700°F
Size: 680 by 820 mm (26.75 by 32.25 in.)
Pad of 50
ADJD034105

Chart VI—Kinematic Viscosity, Low Range:
Kinematic Viscosity: 0.18 to 3.0 cSt
Temperature: − 100 to + 700°F
Size: 520 by 820 mm (20.5 by 32.25 in.)
Pad of 50
ADJD034106

Chart VII—Kinematic Viscosity, Middle Range:
Kinematic Viscosity: 3 to 200 000 cSt
Temperature: − 40 to + 150°C
Size: 217 by 280 mm (8.5 by 11.0 in.)
Pad of 50
ADJD034107

4.2 Charts I, II, V, and VI are preferred when convenience and accuracy of plotting are desired. Chart VII is the middle range section of Chart I at somewhat reduced scale. It is provided for convenience in connection with reports and data evaluation. Charts III and IV are the same as Charts I and II and are provided in greatly reduced scale for convenience in connection with reports or quick evaluation of data. These latter charts are not recommended for use where the most accurate interpolations or extrapolations are desired.

5. Procedure

5.1 Plot two known kinematic viscosity-temperature points on the chart. Draw a sharply defined straight line through them. A point on this line, within the range defined in Section 3, shows the kinematic viscosity at the corresponding desired temperature and vice versa.[4]

[4] If the kinematic viscosities are not known, they should be determined in accordance with Test Method D 445.

6. Extrapolation

6.1 Kinematic viscosity-temperature points on the extrapolated portion of the line, but still within the range defined in Section 3, are satisfactory provided the kinematic viscosity-temperature line is located quite accurately. For purposes of extrapolation, it is especially important that the two known kinematic viscosity-temperature points be far apart. If these two points are not sufficiently far apart, experimental errors in the kinematic viscosity determinations and in drawing the line may seriously affect the accuracy of extrapolated points, particularly if the difference between an extrapolated temperature and the nearest temperature of determination is greater than the difference between the two temperatures of determination. In extreme cases, an additional determination at a third temperature is advisable.

7. Keywords

7.1 charts; kinematic viscosity; MacCoull; viscosity; viscosity-temperature charts

APPENDIXES

(Nonmandatory Information)

X1. MATHEMATICAL RELATIONSHIPS

X1.1 The charts were derived[5] with computer assistance to provide linearity over a greater range on the basis of the most reliable of modern data. The general relationship is:

$$\log \log Z = A - B \log T \qquad \text{(X1.1)}$$

where:

Z = $(v + 0.7 + C - D + E - F + G - H)$,
log = logarithm to base 10,
v = kinematic viscosity, cSt (or mm^2/s),
T = temperature, K or °R,
A and B = constants,
C = $\exp(-1.14883 - 2.65868v)$,
D = $\exp(-0.0038138 - 12.5645v)$,
E = $\exp(5.46491 - 37.6289v)$,
F = $\exp(13.0458 - 74.6851v)$,
G = $\exp(37.4619 - 192.643v)$, and
H = $\exp(80.4945 - 400.468v)$.

X1.1.1 Terms C through H are exponentials on the natural base e since this simplifies computer programming. Eq X1.1 uses logarithms to the base 10 for general convenience when used in short form.

X1.1.2 The limits of applicability are listed below:

$Z = (v + 0.7)$	2×10^7 to 2.00 cSt
$Z = (v + 0.7 + C)$	2×10^7 to 1.65 cSt
$Z = (v + 0.7 + C - D)$	2×10^7 to 0.90 cSt
$Z = (v + 0.7 + C - D + E)$	2×10^7 to 0.30 cSt
$Z = (v + 0.7 + C - D + E - F + G)$	2×10^7 to 0.24 cSt
$Z = (v + 0.7 + C - D + E - F + G - H)$	2×10^7 to 0.21 cSt

X1.2 It is obvious that Eq X1.1 in the simplified form: $\log \log (v + 0.7) = A - B \log T$ will permit kinematic viscosity calculations for a given fluid in the majority of instances required. The constants A and B can be evaluated for a fluid from two data points. Kinematic viscosities or temperatures for other points can then be readily calculated.

X1.3 Older literature refers to a value called the ASTM Slope. It should be noted that this value is not the value of B given in Eq X1.1. The ASTM Slope was originally obtained by physically measuring the slope of the kinematic viscosity-temperature data plotted on the older charts given in Method D 341 – 43. The kinematic viscosity and temperature scales were not made to the same ratios in Method D 341 – 43. The improved charts given here utilize even different scale ratios for dimensional convenience and a different constant (0.7) from the older charts; consequently, the original ASTM Slope is not numerically equivalent to B in Eq X1.1 from any of the new charts, nor directly convertible from Eq X1.1.

X1.4 The complete design equation for the chart as given in X1.1 is not useful for inter-calculations of kinematic viscosity and temperature over the full chart kinematic viscosity range. More convenient equations[6] which agree closely with the chart scale are given below. These are necessary when calculations involve kinematic viscosities smaller than 2.0 cSt.

$$\log \log Z = A - B \log T \qquad \text{(X1.2)}$$

$$Z = \nu + 0.7 + \exp(-1.47 - 1.84\nu - 0.51\nu^2 \qquad \text{(X1.3)}$$

$$\nu = [Z - 0.7] - \exp(-0.7487 - 3.295\,[Z - 0.7] + 0.6119\,[Z - 0.7]^2 - 0.3193\,[Z - 0.7]^3) \qquad \text{(X1.4)}$$

where:

log = logarithm to base 10,
ν = kinematic viscosity, cSt (or mm^2/s),
T = temperature, K or° R, and
A and B = constants.

X1.4.1 Inserting Eq X1.3 into Eq X1.2 will permit solving for the constants A and B for a fluid in which some of the experimental kinematic viscosity data fall below 2.0 cSt. This form can also be used to calculate the temperature associated with a desired kinematic viscosity.

X1.4.2 Conversely, the kinematic viscosity associated with a stated temperature can be found from the equation determined as in X1.4.1 by solving for Z in the substituted Eq X1.2, and then subsequently deriving the kinematic viscosity from the value of Z by the use of Eq X1.4.

[5] Wright, W. A., "An Improved Viscosity-Temperature Chart for Hydrocarbons," *Journal of Materials*, Vol 4, No. 1, 1969, pp. 19–27.

[6] Manning, R. E., "Computational Aids for Kinematic Viscosity Conversions from 100 and 210°F to 40 and 100°C," *Journal of Testing and Evaluation*, JTEVA, Vol 2, No. 6, 1974 pp. 522–8.

X2. OIL BLENDING CALCULATIONS

X2.1 Predicting the volume fractions of two given oils when blending to meet a specified kinematic viscosity at a given temperature is a common problem. A number of blending calculation techniques have been used. The Wright method described here is preferred since it automatically allows for the effects of oil type, molecular weight and viscosity index of component oils. This results in greater accuracy, particularly where component oil kinematic viscosities or types differ significantly.

X2.2 Two methods are given below:

X2.2.1 A plotting technique on ASTM viscosity temperature charts. See X2.3.

X2.2.2 Calculation on a pocket calculator (preferably a programmable calculator or a computer). See X2.4.

X2.2.3 In either case, the required data are the kinematic viscosities of each component oil at 40 and 100°C and the desired kinematic viscosity of the oil blend at one of these temperatures.

X2.3 Plot the known data for each component on an ASTM Viscosity-Temperature Chart and carefully draw straight lines through the points. The lines should extend beyond the blend kinematic viscosity required. Locate, or draw, the desired blend kinematic viscosity horizontal line on the chart through both of the component oil lines. Lay a centimetre scale along this line and carefully measure the distance between the lines for the two oils where they cross the line of the desired blend kinematic viscosity. Without moving the scale, on the same horizontal kinematic viscosity line read the distance from the low viscosity oil line to the temperature desired. Dividing the latter by the first measurement between the two oils gives the volume fraction needed for the high viscosity oil.

X2.3.1 An example of the above method is as follows:

Given:	low viscosity oil	$\nu_{(40°C)}$	= 55.7 cSt
		$\nu_{(100°C)}$	= 7.50 cSt
	high viscosity oil	$\nu_{(40°C)}$	= 190.00 cSt
		$\nu_{(100°C)}$	= 17.00 cSt

Determine: Volume fraction of the high viscosity oil for a blend of 13.00 cSt at 100°C.

Fig. X2.1 is a segment of Chart VII. From Fig. X2.1, the distance from the low viscosity oil to 100°C along the 13.0- cSt line is 2.26 cm. The distance from the low viscosity oil to the high viscosity oil along the 13.0-cSt line is 3.30 cm. The volume fraction of the high viscosity oil is as follows:

$$\text{Volume fraction (high kinematic viscosity)} = \frac{2.26}{3.30} = 0.685 \tag{X2.1}$$

X2.4 The required blend may also be calculated using a

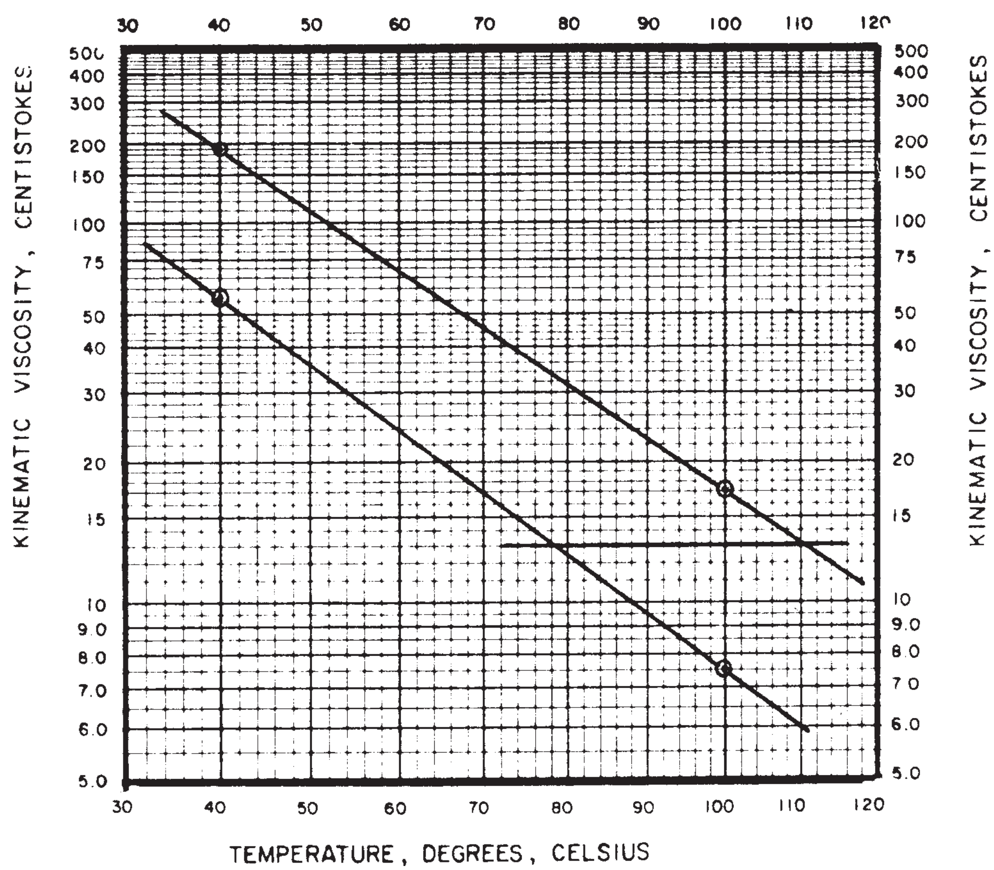

FIG. X2.1 Oil Blending Calculations

calculator or computer. The relationships are at 40°C:

$$\text{volume fraction high viscosity oil} = \left[\frac{(E - A)\,(C - D)}{(E - F)\,(A - C)} + 1 \right]^{-1} \quad \text{(X2.2)}$$

at 100°C:

$$\text{volume fraction high viscosity oil} = \left[\frac{(F - B)\,(C - D)}{(E - F)\,(B - D)} + 1 \right]^{-1} \quad \text{(X2.3)}$$

where:

A = log log $Z_{B(40)}$
B = log log $Z_{B(100)}$
C = log log $Z_{L(40)}$
D = log log $Z_{L(100)}$
E = log log $Z_{H(40)}$
F = log log $Z_{H(100)}$
Z = (cSt + 0.70)

Subscripts:
B = blend
L = low-viscosity oil
H = high viscosity oil
(40) = 40°C
(100) = 100°C

X2.4.1 An example of this second method using the data in X2.3.1 is as follows:

B = 0.05565
C = 0.24336
D = −0.03914
E = 0.35800
F = 0.09621

Volume fraction high viscosity oil at 100°C

$$= \left[\frac{(0.09621 - 0.05565)\,(0.24336 + 0.03914)}{(0.35800 - 0.09621)\,(0.05565 + 0.03914)} + 1 \right]^{-1} = 0.684 \quad \text{(X2.4)}$$

X2.5 It may be noted that the same general methods of calculation can be adapted for use with other temperatures. If the kinematic viscosity-temperature data must be extrapolated to temperatures far above or below the data, the accuracy of the calculation may be significantly lessened.

X2.6 The oil blending calculations can be done more conveniently by computer. One program in BASIC that is convenient to use has been published.[7]

[7] Huggins, P., "Program Evaluates Component and Blend Viscosities," *Oil and Gas Journal*, Vol 83, No. 43, 1985, pp. 122–129. Copies of a similar program derived from this program are available from Cannon Instrument Company, P. O. Box 16, State College, PA 16804-0016.

X3. HISTORY OF THE ASTM VISCOSITY-TEMPERATURE CHARTS

X3.1 The forerunner of these charts was published by Neil MacCoull[8]. His continuation of the study of these charts resulted in publication in 1927[9] of the chart based on

$$\log \quad \log\,(\text{cSt} + 0.7) = A - B \log \; T \quad \text{(X3.1)}$$

An ASTM committee undertook study of this chart at that time, resulting in the first ASTM chart publication in 1932 using a constant of 0.8 in the equation. The constant was allowed to vary in charts published after 1937.

X3.2 Walther published in 1928 the log-log equation (*5*) without the constant and in 1931 the log-log equation with a constant of 0.8.

X3.3 The present MacCoull-Wright charts are based largely on the work of MacCoull, Wright,[5] and ASTM Subcommittee D02.7.

[8] MacCoull, N., *Lubrication*, The Texas Company, New York, June 1921, p. 65.
[9] *1927 International Critical Tables*, p. 147.