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A GUIDE TO THE VISCOSITY OF LIQUID PETROLEUM PRODUCTS

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Continued on inside back cover



71003

A GUIDE TO THE VISCOSITY OF LIQUID PETROLEUM PRODUCTS

CONTENTS

	Page
1. NOTATION AND UNITS	3
2. INTRODUCTION	3
3. EFFECT OF TEMPERATURE ON VISCOSITY AND DENSITY	4
4. EFFECT OF PRESSURE ON VISCOSITY	4
5. VISCOSITY OF BLENDS	5
6. EXAMPLES OF THE CALCULATION OF THE VISCOSITY OF A BLEND	6
7. GLOSSARY AND INDEX TO DATA	6
8. REFERENCES	12
TABLES I - III	14 - 17
FIGURES 1 - 6	18 - 23

Issued January 1971 - 23 pages



1. NOTATION AND UNITS

		SI Unit	Unit being adopted by the petroleum industry
p	pressure	N/m^2	lbf/in^2
T	absolute temperature	K	K
t	temperature	K	$^{\circ}\text{C}$
η	dynamic viscosity	N s/m^2 (poiseuille)	cP (centipoise)
* ν	kinematic viscosity	m^2/s	cSt (centistokes)
** ρ	density	kg/m^3	kg/litre

2. INTRODUCTION

Petroleum products are usually specified by *ranges* of values of several properties rather than by any *exact* values. This Memorandum shows on Figures 1 - 4 the approximate ranges of kinematic viscosity most commonly covered by various classes of liquid petroleum product. Table I indicates the maximum ranges likely to be covered by the listed products. A more accurate value for the viscosity of a particular product within any class will usually be available from the supplier. If an actual measurement has to be made, the methods outlined in British Standard 188¹² are recommended. Similar procedures are given in the Institute of Petroleum Standard 71²³ and ASTM Standard D-445²².

An index to the data on the Figures and in Table I and a glossary of some terms commonly used in the petroleum industry are given in Section 7 of this Memorandum.

Synthetic materials which are chemically different from petroleum products are not included. Greases are also excluded, because they are non-Newtonian fluids.

When the petroleum industry specifies the viscosity of any of its products it usually employs the kinematic viscosity, but for many purposes the dynamic viscosity is required. Table I gives approximate data for the dynamic viscosities of various classes of product. These values were computed from the kinematic viscosities using a mean density for each class of product.

† The use of the Celsius scale is now preferred but it is common practice to quote also the equivalent in $^{\circ}\text{F}$. Many specifications and test methods are based on temperatures which are round values in $^{\circ}\text{F}$.

* Although kinematic viscosities are frequently quoted in terms of an arbitrary unit such as the Redwood second or the Saybolt second, a rational unit, usually the centistokes, is employed in most test methods and is much to be preferred. Reference 19 includes a conversion table which allows conversion from centistokes to some of the arbitrary units. Because of the much higher accuracy of the methods for determining kinematic viscosities in fundamental units, exact conversion from arbitrary units is not realistic. However, provided that it is remembered that the conversion is not exact, the table in Reference 19 may be used to obtain equivalents of the arbitrary units in centistokes. Reference 19 also includes conversion factors for other units of kinematic and dynamic viscosity.

** The specific gravity or relative density (i.e. density relative to that of water) of a petroleum product is often quoted instead of its density. (See also API gravity in Section 7.)

3. EFFECT OF TEMPERATURE ON VISCOSITY AND DENSITY

The variation of kinematic viscosity with temperature for any liquid petroleum product is such that a plot of $\log \log (\nu + \text{constant})$ against $\log T$ approximates to a straight line. The lines for the lighter products, notably the liquefied petroleum gases, are likely to show most curvature. The slope of the line depends on the chemical constitution and viscosity level of the product, heavier products tending to show rather steeper slopes than the light ones. However, all "straight" distillation products (i.e. products separated by distillation only and containing no property-modifying additives) from one particular crude petroleum will show nearly equal slopes. Further refining processes which may be carried out in addition to distillation modify the slope; for example, removal of some of the aromatic hydrocarbons reduces it.

Standard charts* are available with scales proportional to $\log \log (\nu + \text{constant})$ and $\log T$, which permit simple graphical interpolation if the kinematic viscosities at two temperatures are known. Extrapolation is permissible but care must be taken to avoid the regions of wax precipitation (below the cloud point or the pour point) or of vaporisation or decomposition.

For lubricating oils a commonly used measure of the variation of kinematic viscosity with temperature is the *viscosity index*. The nature of this index is described briefly in the Glossary (Section 7) and references are given to more detailed explanations. Although widely used the method is not ideal¹⁹ because of its arbitrary basis. Table II relates the kinematic viscosities at two reference temperatures (37.8°C, 100°F and 98.9°C, 210°F) to the corresponding viscosity index. It is based on data from Reference 14 (which gives more extensive tables). If the viscosity at one reference temperature and the viscosity index are known, the viscosity at the other temperature may be found from Table II and interpolation on one of the previously mentioned charts is then possible.

Figures 1 - 4 of this Memorandum show typical magnitudes and temperature variations of kinematic viscosity for various classes of petroleum product. The data are based principally on References 3, 4, 7, 10, 11 and 15.

The effect of temperature on the density of liquid petroleum products may be represented with sufficient accuracy for most practical purposes by the linear variations shown in Figure 6 for products of various densities.

4. EFFECT OF PRESSURE ON VISCOSITY

The effect of pressure on the viscosity of liquids in general is discussed in Reference 19. The effect on the lighter petroleum products is small but as the mean molecular weight and complexity of the molecules increases, the effect of pressure on the viscosity of the product also increases. Figure 5, based on data from References 1 and 2, shows the order of the pressure effect on the dynamic viscosity of lubricating oils which have not been substantially modified by additives.

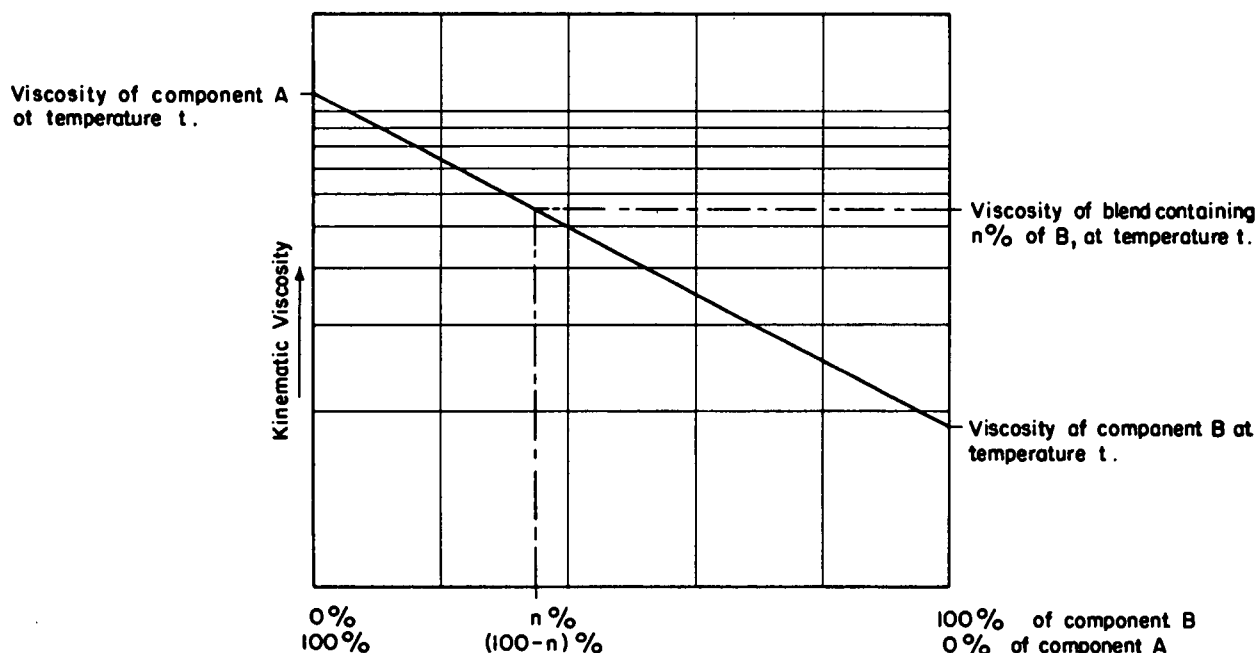
* Examples are the Refutas chart available from Baird and Tatlock, Freshwater Road, Chadwell Heath, Essex, and the several ASTM charts, available in the United Kingdom from the Institute of Petroleum, 61 New Cavendish Street, London W1M 8AR. A chart similar to the Refutas chart is produced by the British Petroleum Co. Ltd and is available from John Hartley and Partners Ltd, 36 Great James Street, London, WC1N 3HB.



5. VISCOSITY OF BLENDS

For predicting the viscosities of blends of two petroleum products, a method based on the standard kinematic viscosity-temperature charts gives satisfactory results. It is most reliable for blends of products derived from similar sources and not too widely separated in viscosity.

The temperature scale of the chart is replaced by a 0-100 per cent linear scale representing the proportion of one component of the blend. The viscosity of a blend containing n per cent** of one component is linearly interpolated between the viscosities of the two components at the same temperature, as shown in the diagram below.



The method can conveniently be extended to multicomponent blends by using Table III which gives values of a kinematic viscosity function based on the Refutas* kinematic viscosity-temperature chart. The kinematic viscosity function for the blend is found by summing the products of viscosity function and percentage** of each component at the same temperature and dividing the sum by 100. The kinematic viscosity function is then converted back to a viscosity value by using Table III. It is emphasised that this table is based on viscosities in centistokes and if the viscosities of the blend components are given in any other units they must be converted† to centistokes before the method is applied.

* See footnote on page 4.

** The method is based on percentage by weight but if the densities of the components do not differ greatly then percentage by volume may be used.

† Reference 19 gives a number of conversion factors. See footnote on page 3.

6. EXAMPLES OF THE CALCULATION OF THE VISCOSITY OF A BLEND

1. Estimate the kinematic viscosity at 50°C of a blended oil of the following composition: 15 per cent oil A (kinematic viscosity 24 cSt at 50°C), 35 per cent oil B (kinematic viscosity 18 cSt at 50°C) and 50 per cent oil C (kinematic viscosity 42 cSt at 50°C).

Using Table III, the kinematic viscosity functions of the components are: for A, 27.93; for B, 26.62; and for C, 30.21. Thus the kinematic viscosity function of the blend

$$= \frac{(15 \times 27.93) + (35 \times 26.62) + (50 \times 30.21)}{100}$$

$$= 28.61$$

From Table III this corresponds to a kinematic viscosity of approximately 28 cSt.

2. What will be the approximate kinematic viscosity at 37.8°C, 100°F, in ft²/h, of an oil blended from 60 per cent oil D (kinematic viscosity 1.0 ft²/h at 100°F) and 40 per cent oil E (kinematic viscosity 0.85 ft²/h at 100°F)?

First convert† the viscosities given to centistokes.

$$\text{Viscosity of oil D} = 1.0 \times 25.8 \text{ cSt} = 25.8 \text{ cSt.}$$

$$\text{Viscosity of oil E} = 0.85 \times 25.8 \text{ cSt} = 21.9 \text{ cSt.}$$

Using Table III, the kinematic viscosity function of the blend

$$= \frac{(60 \times 28.24) + (40 \times 27.53)}{100} = 27.96$$

From Table III this corresponds to a kinematic viscosity of approximately 24 cSt. Converting† this back to ft²/h, the viscosity of the blend is approximately 0.95 ft²/h at 98.9°C, 100°F.

7. GLOSSARY AND INDEX TO DATA

Table and figure numbers given in brackets against an entry refer to the table or figure in this Memorandum which gives data for the product concerned.

API gravity (°API)

(American Petroleum Institute.) A scale of density widely used for petroleum products in the USA and used internationally for crude oils.

$$^{\circ}\text{API} = \frac{141.5}{\text{specific gravity } 60/60^{\circ}\text{F}} - 131.5$$

See also specific gravity (relative density).

Aromatic oils

See lubricating oils.

ATG (aviation turbine gasoline) (Figure 1.) See gasolines.

† Reference 19 gives a number of conversion factors. See footnote on page 3.



ATK (aviation turbine kerosine)	(Figure 1.) See kerosines.
Automobile engine oils	See engine oils.
AVCAT	See kerosines.
AVGAS	See gasolines.
AVTAG	See gasolines.
AVTUR	See kerosines.
Benzines	(Table I, Figure 1.) See light distillates.
Bitumens	(Table I, Figure 2. See also Reference 6.) These consist mainly of the residues from vacuum distillation. In the fully molten state they may be regarded as Newtonian fluids, but they lose this property as they cool towards their setting temperature.
Black oils	When used generally the term refers to oils which are not clear in colour. More specifically it is applied to a refined grade of lubricating oil made more adhesive by the addition of bitumens (which darken the colour) for use on open gears and wire ropes.
Bottled gases	See liquefied petroleum gases.
Bright stock	A refined high-viscosity lubricating oil blending component, usually made from certain residues from vacuum distillation.
British Standards Classification of lubricants	Classification for industrial liquid lubricants, applicable to petroleum products. Based on kinematic viscosity in centistokes at 100°F with a permitted range of ± 10 per cent of nominal values. (Figures 2 and 3.) See References 19 and 21.
Butanes	(Figure 1.) See liquefied petroleum gases.
Butenes	(Figure 1.) See liquefied petroleum gases.
Cloud point	The temperature at which a visible cloud of insoluble wax is first formed when an oil is cooled under specified conditions. See References 22 and 23.
Compressor oils	(Table I.)
Control mechanism oils	(Figure 4.) Light grades of machinery oils.
Crankcase oils	(Figure 4.) See engine oils.
Crude petroleum	Petroleum as extracted from the earth. Crude petroleum varies widely in molecular composition but its elemental composition generally lies within the quite close limits of 83-87 per cent carbon, 11-14 per cent hydrogen and 2-3 per cent oxygen, nitrogen and sulphur, all by weight.