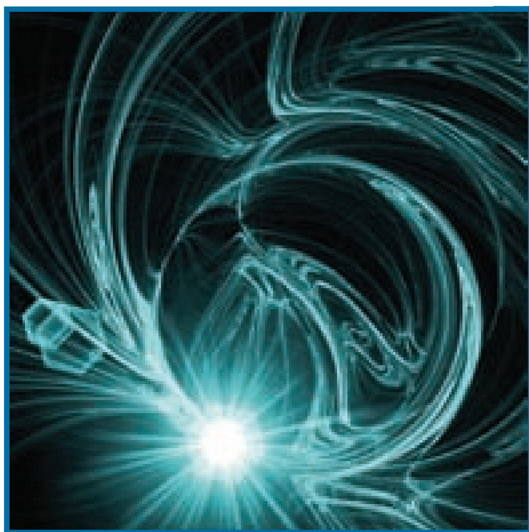

Viscosity Measurements for Petroleum Products

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When the American Society for Testing and Materials (ASTM) came into existence in 1898, its first assignment focused on materials and dimensions for rail tracks. At that time the oil industry was expanding quickly, and procedures for characterising oil products soon started to come within the scope of ASTM. The earliest ASTM standards for the oil industry were concerned with flash points (Jones, 2005). Taking into account the range of applications for petroleum products, from gasoline to heavy residue, viscosity / resistance to flow became important quantities in usage. This created, by the middle of the 20th Century, ASTM standards for the viscosity of petroleum products (Johnson & Auth, 1951). By this time standards bodies had been established in many countries and ISO, an international network of standards bodies, had been formed with its headquarters in Geneva.

Johnson & Auth (1951) cites ASTM D445-2T 'Method of Test for Kinematic Viscosity', and an examination of this follows. Kinematic viscosity has dimensions length2 time^{-1} as do thermal diffusivity and diffusion coefficient. They are analogue quantities, depending on whether momentum, heat or mass is being transferred. What Johnson & Auth (1951) called ASTM D445-2T has now become ASTM D445–12 (ASTM International, 2013), which may well have successive revisions. This standard involves measuring the time taken for the liquid to descend a calibrated capillary. ASTM D445–12 covers the range of kinematic viscosities 0.2 to 300000 mm^2 s^{-1} (2 × 10-7 to 0.3 m^2 s^{-1}) and we note that 10-4 m^2 s^{-1} = 1 stoke. In order that a reader should have a feel for these quantities they are given in tabulated form below for a number of liquids.

Liquid	Kinematic viscosity	Comments
Biodiesel	3.5 to 5 mm^2 s^{-1} at 40°C	Value range given in European Standard 14214 2008, which specifies properties for biodiesels.
Jet fuel	8 centistokes at -20°C	ExxonMobil specification (Exxon Mobil, 2005). Note the equivalence of centistoke and mm2s^{-1}.
Marine lubricant	3.8 to 16.3 centistokes at 100°C	BP specifications (BP, 2013).
'Esso Ultra' motor engine oil (Esso, 2009)	63 to 66 centistokes at 40°C	Product developed for the Canadian market.
Gasolines	0.4 to 0.9 centistokes at 38°C	Approximate range only, taken from (The Engineering Toolbox, 2013).

Figure 1: Viscometer manufactured by Thomas Scientific (Thomas Scientific, 2013).

Figure 2: Cannon Instruments miniAV® (Cannon Instrument Company, 2013).

Before considering instrumentation which conforms to ASTM D445–12 we shall consider further the standard itself and other similar ones. ISO, as a body drawing together and co-ordinating 'standards' worldwide, often adds its own authority to that of a national body having issued a particular standard. This is true of ASTM D445–12 which is also ISO 3104: 1994. Having the same scope and purpose as ASTM D445–12 and ISO 3104: 1994 but not identical in all respects with them are DIN 51366 (Germany) and IP 71 (UK). Instruments for measuring viscosity by these means are widely available. The illustration below is of a viscometer of fairly simple construction designed for measurement according to ASTM D 445 and ISO 3104.

This viscometer is suitable for transparent liquids only and this prevents application with heavy residues. The glasswork shown in the plate is suspended in a water bath to make sure the temperature of measurement is controlled.

Also conforming to ASTM D445 but able to be used for opaque as well as transparent liquids is the Cannon Instruments miniAV® (below).

The Cannon miniAV®, which can be operated at temperatures up to 100°C, has a kinematic viscosity measurement range of 0.3 to 6000 centistokes. This enables it to be used for substances as different as gasoline (lower measurement limit) and hydrocarbon greases (upper measurement limit).

There are many viscometers available for use and often their advertisement features 'ASTM D445' in bold. The two examples chosen above are each compliant with this standard, which has been in use for many decades. They differ in degree of instrumentational advancement, and the fact that both viscometers continue to find application is evidence of the continuing methodology which characterises so much of petroleum technology. Biodiesels at this early stage of their international adoption are precisely specified in kinematic viscosity terms. This is evidence of commitment to their development and the same can be said of the various gasoline/alcohol blends which have become available since carbon footprints of fuels became such an important issue.

Figure 3: Glass capillary master viscometer (PM Tamson Instruments, 2013)

Devices such as those pictured (and there are many more) have to be calibrated against standards, liquids of well characterised viscosity within the range of measurement for that instrument. It often happens that when measuring viscosity, over the whole process, two or more standards are used together. The standard which applies to the calibration is ASTM D2162: Standard Practice for Basic Calibration of Master Viscometers and Viscosity Oil Standards. When ASTM D445 and ASTM D2162 are used in conjunction with each other, as they frequently are, a distinction has to be made between a routine viscometer to which the former applies and a 'master viscometer' to which the latter applies. A glass capillary master viscometer manufactured by Cannon (PM Tamson Instruments, 2013) is shown in plate 3 below.

The difference between a routine and a master glass capillary viscometer is one of degree and depends on the precision of the glassblowing when being manufactured. The calibration standards referred to above will have been tested on a master viscometer in accordance with ASTM D2162 and can then be applied to other viscometers whose users invoke ASTM D445. For example Conostan® (2013) make standards ranging in kinematic viscosity at 40°C from 2.8 to

23000 centistokes. Their kinematic viscosities at other temperatures are also known with the precision expected of an ASTM D2162 product. There are also standards for viscosities at low temperatures such as might be experienced by a jet fuel at full altitude (DC Scientific, 2011). An alert reader may well be wondering why a pure organic compound cannot be used as a reference instead of an expensive standard. This is fine provided that the viscosity of the compound has itself been determined in a master viscometer by ASTM D2162, but reliance on a tabulated value of the viscosity of the pure compound is not satisfactory.

Not only the ‘advanced’ nations but the less so have standards bodies, and this article will conclude with mention of a viscosity specification by a body from a less developed region of the world. IS 15607: 2005, issued by Bureau of Indian Standards, gives the kinematic viscosity range for biodiesels made in India as 2.5 to 6.0 centistokes. This differs a little from the requirements of European Standard 14214 which are given in the above table.

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