We're Going Global

Understanding Oil Viscosity

Viscosity is a measure of a petroleum product's resistance to flow. It is an important property and specification for petroleum products and has a prominent role in our industry.
Think of the effort it takes to drink a thick viscous milkshake through a straw versus plain milk. The higher the viscosity, the harder it is to pump crude oil out of the ground. The viscosity of a fuel determines how well it can be pumped through pipelines and to and from vessels. Viscosity is used to determine preheat for a fuel oil in order to have proper burner tip atomization in a steam boilers. In a diesel engines the correct viscosity is critical to injection pumps and injectors. In addition, the viscosity of many petroleum fuels is important for the estimation of optimum storage, handling, and operational conditions.

Viscosity Testing on Petroleum Products

The term kinematic signifies that the measurement is made while the fluid is flowing under the force of gravity. The kinematic viscosity of an oil is the length of time in seconds required for a fixed volume of the liquid to flow under gravity through the capillary of viscometer tube with a standardized orifice. Throughout the test the viscometer must be fully submerged in an oil bath maintained at a constant temperature and the prescribed test temperature.

The standard method used by our industry is:

ASTM D445 (EN ISO 3104)
Kinematic Viscosity of Transparent and Opaque Liquids.

Pictured on the left is an oil filled constant temperature bath.

Pictured in the middle and to the right are viscometer tubes.

INDUSTRY STANDARD ASTM D445 (EN ISO 3104)

Kinematic Viscosity of Transparent and Opaque Liquids

The time is measured for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer under a reproducible driving head and at a closely controlled and known temperature. The kinematic viscosity (determined value) is the product of the measured flow time and the calibration constant of the viscometer.

Important Factors When Running D445 Kinematic Viscosity

Temperature

- Temperature control is the single most important parameter for obtaining accurate and precise kinematic viscosity measurement.
- This is especially true for petroleum products as their rate of viscosity change per unit temperature is significantly greater than other products.
- A slight variation in temperature can have a large effect on the viscosity of a fluid.
- The bath temperature for the most common measurements, 40°C and 100°C, must be controlled to within +/- 0.02°C. That is an extremely tight window and great care must be taken to achieve this control.

Thermometer

- A specified thermometer or other temperature-sensing device having the specified accuracy and meeting the test method requirements must be used when measuring viscosity.
- The thermometer must be immersed in the bath at the correct depth. It must be calibrated at least yearly to +/- 0.02°C.
- The thermometer ice point should be determined every six months and the correction factor applied.

Bath Temperature Uniformity and Stability

- Bath temperature uniformity and stability are important parameters.
- The entire length of the viscometer must be maintained at the appropriate temperature.
- The type of circulator used, the age of the bath fluid and the bath fluid viscosity impact temperature uniformity.
- The circulator and the viscosity of the bath fluid need to be balanced to provide a uniform temperature throughout the bath. The bath fluid needs to be changed well before it begins to discolor, as the discoloration indicates the fluid has oxidized and the viscosity probably has increased.
- The bath should not be located near a draft which might cause excessive temperature gradients in the bath (such as in a fume hood or under an A/C vent). Temperature stability will be negatively impacted if a second viscometer is added to the test bath during the same time that another adjacent viscometer is being used for a measurement.

Lighting

- There needs to be sufficient illumination of the sample in the tube while in the bath to ensure consistent visual detection of the meniscus crossing the timing lines.
- Care needs to be taken that this lighting device does not affect the bath temperature control and stability.

Viscometers

- Fully annealed, low-expansion borosilicate glass is required for the construction of all viscometers. There are a number of factors to consider when choosing which viscometer size is needed for sample analysis.
- The viscometer must be calibrated to calculate viscosity. The procedure is described in ASTM D446, Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers. Viscosity standards are used to determine the viscometer constant. Although a single standard is sufficient to obtain a constant, the use of two standards covering the capillary range yields a more robust calibration constant. Viscosity standards have an expiration date and should not be used beyond that date. A calibrated viscometer can be purchased with constants at appropriate temperatures. Because the viscometer constant varies as a function of temperature for certain types of viscometers, it is important to calculate the viscometer constant for the temperature at which the sample is being analyzed. Viscometer constants should be verified at least yearly.
- The size of the viscometer must be chosen such that the flow time is at least 200 seconds for manual determinations; otherwise eye-hand coordination will become a significant factor. The operator waits for the meniscus of the fluid to pass the timing lines and uses a clock or stopwatch to measure the flow time. Flow times greater than 200 seconds are required to eliminate possible operator variation.
- The tube must be free from dust or other particles and the fluid should clearly wet the surface of the glass. Typically, several rinses with a sample solvent such as naphtha, followed by a drying solvent such as acetone, and then purging with a dry, dust-free gas such as air or nitrogen, are sufficient. The solvents also must be residue-free on drying.
- When suspended in the temperature bath, the tube should be in the specified vertical position, free from vibration, and at the specified immersion depth. Follow the manufacturer's instructions and those in the test method.

Timing Device

- The timing device must have an accuracy of within +/- 0.07 percent of the reading and must be capable of taking readings within a discrimination of one part in 2,000 or 0.1 second for a 200-second flow time.
- Care must be taken when using electrical timing devices because alternating currents may not provide the required accuracy.

- Timing devices should be checked against a National Institute of Standards and Technology (NIST) reference or other accepted timing reference on a regular basis. Yearly verification is recommended.

Sample Handling

- Filter samples should be taken if particles are visible. This is especially important when analyzing used oils.
- Because the sample should be free of air, it should be allowed to set to disperse the entrained air, if any is present.
- High pH caustic samples will change the calibration constant. As the sample pH increases, the change in the constant increases more rapidly. The smaller the capillary, the faster the constant changes. The tube may need recalibration after a caustic sample is analyzed, although very caustic samples are not found often in the petroleum industry.
- Samples must be equilibrated at the desired test temperature. Up to 30 minutes may be necessary and possibly longer with some materials.
- Two flow time measurements should be obtained for each sample. If the two determinations of kinematic viscosity, calculated from the flow time measurements, agree with the stated determinability limit for the sample type tested, then the average of the two determinations should be reported. If the two determinations do not agree to within the stated determinability, then the measurements must be repeated after the possible causes have been investigated and corrected. A dirty viscometer, incorrect bath temperature or equilibration time are possible culprits.

VISCOSITY CONSIDERATIONS FOR TYPICAL PRODUCTS

ISO 8217 Bunker Fuel Viscosity

The Test Method for Bunker Fuel is ISO 3104
Petroleum products - Transparent and opaque liquids - Determination of Kinematic Viscosity and Calculation of Dynamic Viscosity. The ASTM equivalent method is ASTM D445.

Viscosity considerations for Bunker Fuel:

- Viscosity is a measure of oil's resistance to flow and it varies with temperature.
- As heavy oil is heated the viscosity is reduced and it will flow more easily.
- Knowledge of bunker fuel viscosity is important to determine temperature for handling, the size of the centrifuges and the temperature at which the fuel is injected into the engine.
- Viscosity greater than specified may affect pumpability, preheating, settling separation, spray formation, atomization and combustion.

- Overly viscous oil can produce problems throughout the system, mainly difficulty pumping, burner hard start and erratic operation.
- The maximum viscosity of the fuel that can be used in an engine depends on the heating facilities available.
- Caution should be taken not to heat the fuel too hot. Overly hot fuel may turn to gas at the injection pumps preventing the generation of proper injection pressure.

ASTM D396 Boiler Fuel Viscosity

Viscosity considerations for No. 6 Fuel Oil for boilers:

- Viscosity or resistance to flow is indicative of how the oil will flow in fuel systems and the ease with which it can be atomized in a given type of burner.
- The viscosity of a heavy fuel decreases rapidly with increasing temperature.
- Heavy fuels can be handled and atomized properly by preheating before use.
- Overly viscous oil can produce problems throughout the system. Difficulty pumping, burner hard start and erratic operation.
- Viscosity also affects delivery angle of a spray nozzle.
- With improper viscosity at the burner tip, poor atomization results in carbonization of the tip, carbon deposits on the walls of the fire box or other conditions leading to poor combustion.

In the example to the right, the No. 6 Fuel Oil has a viscosity of 150 SSF at 122F and the desired nozzle viscosity at the burner is 125 SSU.

To achieve proper atomization, the oil must be preheated to 218°F.

PREHEAT TEMPERATURES TO ACHIEVE PROPER NOZZLE VISCOSITY

FUEL VISCOSITY		DESIRED NOZZLE VISC		PREHEAT °F REQUIRED	
SSF@122	SSU@100	100SSU	125SSU	150SSU	175SSU
50	975	182	178	164	160
75	1582	207	194	184	177
100	2216	220	206	195	188
125	2873	226	212	202	194
150	3549	231	218	206	199
175	4242	236	222	211	204
200	4950	241	226	216	208
225	5671	244	230	218	211
250	6404	247	233	222	214
275	7148	250	236	224	217
300	7903	254	239	228	220

ASTM D975 Diesel Fuel Viscosity

Viscosity considerations for Diesel Fuel:

- For some engines it is advantageous to specify a minimum viscosity because of power loss due to injection pump and injector leakage.
- Maximum viscosity is limited by considerations involved in engine design and size, and the characteristics of the injection system.
- Fuel viscosity exerts a strong influence on the shape of fuel spray. High viscosities can cause poor atomization, large droplets, and high-spray jet penetration. With high viscosities, the jet tends to be a solid stream instead of a spray of small droplets. As a result, the fuel is not distributed in, or mixed with, the air required for burning. This results in poor combustion, accompanied by loss of power and economy. In small engines, the fuel spray may impinge on the cylinder walls, washing away the lubricating oil film and causing dilution of the crankcase oil. Such a condition contributes to excessive wear.
- Low fuel viscosities result in a spray that is too soft to penetrate far enough in the combustion chamber for good mixing. Combustion is impaired and power output and economy are decreased. Low viscosity can lead to excessive leakage past the injection pump plunger. Fuel metering becomes inaccurate and engine efficiency is reduced.

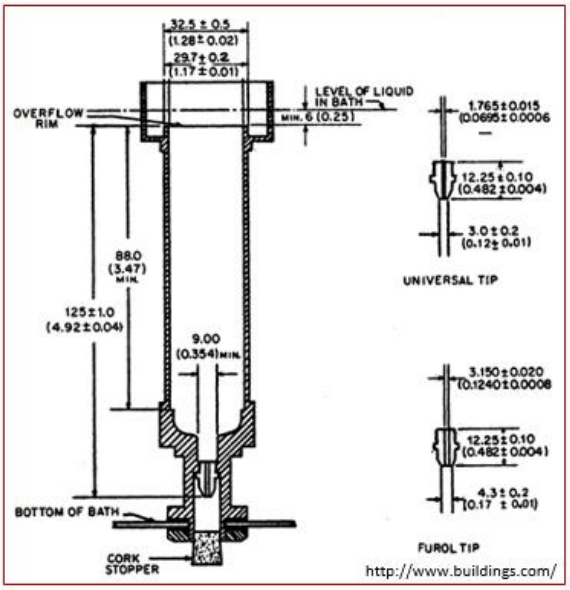
ASTM D1655 Aviation Fuel Viscosity

- In order for jet fuel to endure long cold soak periods at temperatures believed to be -40°C or lower, knowing the viscosity of jet fuel at such low temperatures becomes increasingly important. This is especially relevant for so-called Auxiliary Power Units (APUs), which are small gas turbines that need to start up on command.
- Fuel viscosity at low temperature is limited to ensure that adequate fuel flow and atomization are maintained under all operating conditions and that fuel injection nozzles and system controls will operate to design conditions.
- The primary concern is over engine starting at very low temperatures, either on the ground or at altitude relight.
- Fuel viscosity can also significantly influence the lubricating property of the fuel that, in turn, can affect the fuel pump service life.

OTHER ASTM TESTS

ASTM D88 - 07(2013)
Standard Test Method for Saybolt Viscosity

The Saybolt Furol viscosity is approximately one tenth the Saybolt Universal viscosity, and is recommended for characterization of petroleum products such as fuel oils and other residual materials having Saybolt Universal viscosities greater than 1000 seconds.



ASTM D2161
Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity

At one time the petroleum industry relied on measuring kinematic viscosity by means of the Saybolt viscometer, and expressing kinematic viscosity in units of Saybolt Universal Seconds (SUS) and Saybolt Furol Seconds (SFS). The term Furol was derived from ‘fuel and road oil’ and was used to test heavy oils like asphalt. The SSF orifice size is much larger than the SUS orifice.

ASTM D446
Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers

This standard covers some widely used viscometers suitable for use in accordance with Test Method D445. Other viscometers of the glass capillary type which are capable of measuring kinematic viscosity within the limits of precision given in Test Method D445 may be used.