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WHITE PAPER

Guide to Measuring Oil Viscosity

Background

The most important physical property of a lubricating oil is viscosity. Viscosity determines the load carrying ability of the oil as well as how easily it circulates. The correct balance between high viscosity for load carrying and low viscosity for ease of circulation must be considered for any lubricant and its application. Oil provides benefits in addition to lubrication, and it is vital that it be able to flow under all conditions. When in use, contaminants such as water, fuel entering the oil, oxidation, and soot all affect the viscosity. Therefore viscosity measurement is one of the more important tests for oil in a mechanical system.

For machine condition monitoring, kinematic viscosity, defined as the resistance to flow under gravity, is the established method.

The viscosity of oil is impacted by:

- **Temperature variations** – The Viscosity Index (VI) of a lubricating fluid refers to how much the viscosity of the oil changes with temperature. A high VI indicates the oil undergoes little viscosity change due to temperature fluctuations, while a low VI indicates a relatively large viscosity change. Oil with a viscosity that does not change much between 40°C and100°C will have a higher VI than an oil with a greater change in viscosity. The Viscosity Index Test (ASTM D 2270) is based on the Kinematic viscosity of the oil at 40°C (104°F) and 100°C (212°F). Viscosity index numbers above 95 are considered high. Oils with a high VI provide more protection to critical components over a wide range of temperatures.
- **Additives** – Additives can be part of the formulations of oils. For example ,multigrade mineral-based engine oils (except naturally high VI base oils) are formulated with a springy additive that is compact at low temperatures and expands at high temperatures in response to increasing fluid solvency.
- **Thermal and oxidative degradation by-products** – These by-products are insoluble but are carried by the oil in a stable suspension.
- **Soot** – Commonly encountered in diesel engines, soot is a particle that results in a colloidal suspension in the oil. The oil's dispersant additive, designed to keep soot particles from agglomerating and growing, facilitates the formation of a colloidal suspension.
- **Water contamination** – Oil and free water don't mix, not chemically anyway. But under certain circumstances, they will combine to form an emulsion which looks like coffee with cream, and this will actually increase the kinematic viscosity of oil.

Kinematic viscosity υ, describes a substance's flow behavior under the influence of Earth's gravity. It is the dynamic viscosity divided by density ρ (rho). Density is defined as mass per volume.

$$\nu = \frac{\eta}{\rho}\left[\frac{m^2}{s}\right] \qquad \rho = \frac{m}{V}\left[\frac{kg}{m^3}\right]$$

Kinematic viscosity is widely established due to historical reasons: Gravity as the driving force does not require any elaborate technical equipment and is constant everywhere on Earth.

The SI unit is square-meters per second [m^2/s] or square-millimeters per second [mm^2/s]: **1 m^2/s = 1 000 000 mm^2/s**

The SI units can be derived from the equation for the kinematic viscosity:

$$\left[\frac{m^2}{s}\right] = \left[\frac{Pa \cdot s}{\frac{kg}{m^3}}\right] = \left[\frac{\frac{N}{m^2} \cdot s}{\frac{kg}{m^3}}\right]$$

$$[N] = \left[\frac{kg \cdot m}{s^2}\right]$$

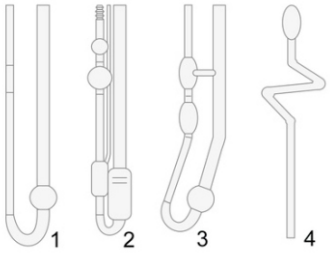
$$\left[\frac{m^2}{s}\right] = \left[\frac{kg \cdot m}{s^2 \cdot m^2} \cdot s \cdot \frac{m^3}{kg}\right]$$

Other commonly used units are stokes [St] or centistokes [cSt]: **1 St = 100 cSt**

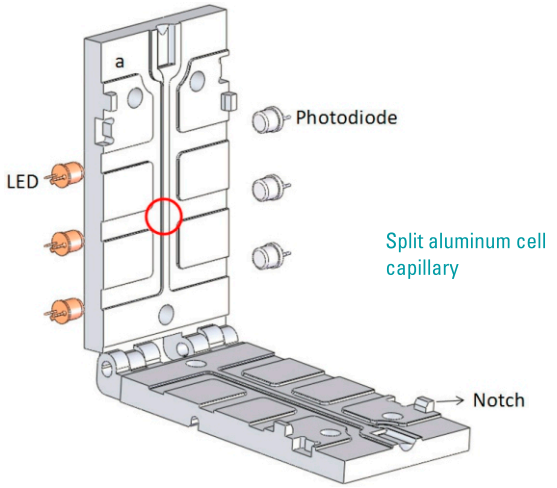
Measuring kinematic viscosity

Gravimetric Capillary – The most widely used technique for measuring kinematic viscosity is the use of a Gravimetric Capillary that is temperature controlled, usually 40 C for single grade oils, and both 40 and 100 C for multigrade oils. Measurements using capillary viscometers are based on the relation between viscosity and time. The more viscous an oil, the longer it will take to flow through a capillary under the influence of gravity alone.There are several standardized capillaries in use today. Most laboratory instruments employ glass capillaries, or 'tubes.' A more recent advancement for field measure of kinematic viscosity employs a split aluminum cell capillary

The instruments are designed to work as either direct-flow or reverse-flow capillaries. In direct-flow capillaries, the sample reservoir is located below the measuring marks. In reverse-flow types the reservoir sits above the marks. Reverse-flow capillaries allow the testing of opaque liquids and some can have a third measuring mark. Having three measuring marks provides two subsequent flow times and improves the measurement repeatability.



GLASS CAPILLARY TYPES
1 – Ostwald (direct)
2 – Ubbelohde (direct)
3 – Cannon-Fenske (direct)
4 – Houillon (Modified Zeitfuchs crossarm) reverse flow)



Split aluminum cell capillary

Common types of kinematic viscometer

MANUAL CONSTANT TEMPERATURE BATH SYSTEMS

Cannon Instrument Company constant temperature bath

These systems consist of a very precise temperature controlled bath, in which the direct flow capillaries are immersed. A sample of oil, usually 10 ml, is suctioned into the tube until it reaches the start point. The suction is then released and the oil flows by gravity through the controlled capillary section of the tube. Two or three marks are visible on the tube. An operator watches the meniscus of the oil as it passes the start point. At this point, the operator times how long it takes the oil to pass the final mark. The tubes are selected such that the test will take a minimum of 200 secs to complete. This makes it easier for manual timekeeping. ASTM D 445 is the method for kinematic viscosity and was originally written for the manual method.

PROS
- Inexpensive
- Accurate
- Easy tube replacement

CONS
- Slow and requires operator to manually watch time (10 samples per hour typical)
- Tubes must be cleaned manually
- At least 10 ml of oil required
- Opaque/dark oils require additional steps

AUTOMATED MODIFIED UBBELOHDE METHOD

Automated Ubbelohde viscometer

A common system used by labs is an automated modified Ubbelohde method. A 10 ml bottle is placed in a small carousel rack. The system draws oil up to the tubes as per the manual method, though in this case all the tasks are controlled by a computer program. The system does not require an operator to monitor and time the oil flow.

PROS
- Automation carousel for sample loading
- Automation – self-cleaning and drying tubes and sample vials
- Dual solvent option for hard to clean sooty oil samples

CONS
- Slow – 12 samples per hour (10 position carousel)
- Two tubes fixed in place – less flexibility
- High solvent usage during self cleaning (15 ml per sample)
- Sample volume – 5 ml per measurement minimum

DIRECT FLOW CAPILLARIES

Spectro Scientific SpectroVisc Q300 kinematic temperature bath viscometer

These systems are preferred for in-service condition monitoring because they are more suitable for opaque fluids, and the lab versions have higher throughput and flexibility. Common names for this method are “Houillon” or “Hele-Shaw” technique. The ASTM method that describes this approach is ASTM D7279. A frequent question for anyone considering obtaining a viscometer is how does this method compare to ASTM D 445, a far more widely known viscosity method. ASTM D 7279 has excellent repeatability, and to obtain identical ASTM D445 results, a standard offset (detailed in the method) is all that is required. For most users who are focused on the trend change, laboratory instruments designed using this technique have excellent accuracy and exceed machine condition monitoring requirements.

PROS
- Low sample volume (0.6 ml)
- High throughput – 25 to 45 samples per hour
- 4 tubes per bath – easy tube replacement (less than 1 minute to swap, without bath draining)
- Semi-Automation – Self-cleaning and drying tubes and sample vials
- Dual solvent option for hard to clean sooty oil samples
- Dual measurement options (sample measured twice on same tube) for high accuracy new oil blending QC

CONS
- Automated sample loading is not standard
- High solvent usage during self-cleaning (15 ml per sample)
- Houillon capillaries susceptible to stuck particles

To take a measurement using this technique a small sample of oil, between 0.6 to 1.6 ml, is pipetted and introduced directly into the tube that is heated to the desired temperature. Disposable pipette tips are used to minimize cross contamination.

SpectroVisc Q3000 portable direct flow capillary viscometer

■ PORTABLE, SOLVENT FREE DIRECT FLOW CAPILLARY VISCOMETER

Field or mobile applications where a kinematic viscosity result is required can be satisfied with a new generation of viscometers based on the Hele-Shaw split cell capillary design. A single heated aluminum block with a machined capillary enables temperature controlled viscosity at 40 C without use of solvents for cleaning.

PROS
- Low sample volume (0.06 ml)
- Solvent free
- Direct measurement a 40C
- Easy to use for an unskilled operator

CONS
- Plate needs to be conditioned before measurements by prewetting with oil
- Indirect measurement of viscosity at 100 C with VI supplied
- Manual cleaning required

As with lab systems, a 60 microlitre sample is pipetted and introduced to a temperature controlled cell, usually set at 40 C. The device reports the kinematic viscosity directly on the screen when complete. After testing, the operator cleans the plates vigorously with a cleaning pad, and the cell is warmed for the next sample.

Important Conclusions

Viscosity is a critical fluid property, and viscosity monitoring is essential to oil analysis. Be sure to investigate kinematic viscosity measurement techniques for used oils, and be aware that methods differ slightly. It is important that the details of viscosity measurement are understood, so accurate lubrication decisions can be made.

When looking for an onsite viscometer, don't look for complete agreement between the laboratory's kinematic viscometer and the onsite instrument, especially for field systems. Consider the technique, the conditions and user environment. Are solvents difficult to obtain or maintain? Is the equipment being used routinely? Always baseline the new oil with the same viscometer you are using with the in-service oil.

Crea Laboratory Technologies | Unit 4, 4 Teamster Close, Tuggerah NSW 2259
+61 1300 522 725 | www.crealt.com.au | service@crealt.com.au |