Recent Advances in Instrumentation for Viscosity Testing and a Comparative Analysis with Newly Developed Viscometry Instrumentation

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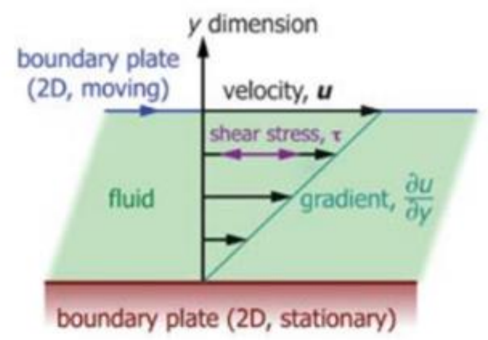
INTRODUCTION

Viscosity is a fluid's resistance to deformation from shear stress, and can be thought of as the fluid's resistance to flow. The viscosity of a fluid comes from the magnitude of internal molecular resistance to motion, where a fluid will only flow if enough force is applied to overcome the internal forces of the fluid, and this force is typically referred to as the shear force. There are two types of viscosity: dynamic and kinematic. Dynamic viscosity is used when considering a fluid's resistance to flow when a shear stress is applied. Kinematic viscosity is used when considering a fluid's resistance to flow when under the effects of gravity. Dynamic and kinematic viscosity are related to each other, as kinematic viscosity is equal to dynamic viscosity divided by the density.

Isaac Newton successfully created a model to mathematically define the viscosity of a fluid. He defined viscosity as the ratio of the force creating the flow in a fluid, or shear stress, to the rate in which the fluid flows in response to that force, or shear rate. This relationship can be shown by the equations below. In these equations, u is the velocity of the fluid, r and y are the relative positions of the fluid, and τ is the shear stress. Newton's relationship is an idealized one, and only applied to Newtonian fluids. In many fluids, the viscosity behavior is more complex, where the relationship between shear stress and shear ate is not linear.

$$\mu = \frac{\tau}{du/dy}$$

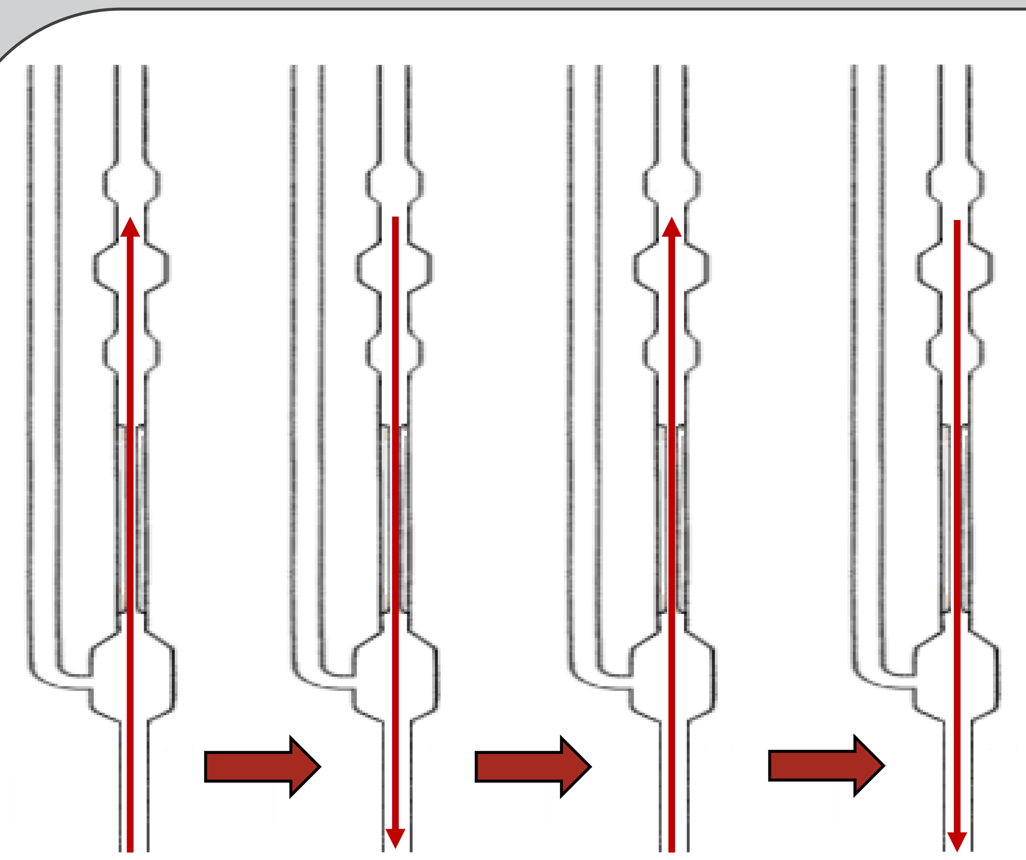
$$\mu = \frac{\tau}{du/dr}$$



The value of viscosity varies depending on the substance and the temperature. Viscosity will decrease with an increase in temperature. In practical scenarios, issues may arise if operating temperatures for the fluid vary over a large range. This is a common problem for lubricating oils. Viscosity index modified can be added to a fluid to help control the effect of changing temperature on the viscosity. If polymer additives are used as a VI modified, "permanent viscosity loss" must be considered. This occurs when the large polymer additives physically break, resulting in an unrecoverable loss to the viscosity.

Viscosity is an important property to consider for many products, such as fuels, lubricating oils, and greases. Therefore, it is required to have standardized methods to measure the viscosity of these products. ASTM D445 is the method to measure the viscosity of a wide range of petroleum products, and have been in use for over 80 years. ASTM D2170 measures the viscosity of highly viscous samples, like asphalts and bitumen. ASTM D7279 also measures the viscosity of a wide range of samples, but specifically uses an automated Houillon viscometer.

OPERATION OF ASTM D445



If the determinability of the two flow time measurements conforms to ASTM D445, calculate the kinematic viscosity.

$$\nu = c * t$$

where
ν = kinematic viscosity, cSt
c = tube constant, cSt/s
t = average flow time, s

NEWLY DEVELOPED INSTRUMENTATION

Along with improvements to the ASTM D445 method, new instrumentation associated with the method have been developed to further improve testing procedures and to provide greater flexibility, automation, and versatility. These new instruments help satisfy the demands of the market; including ease of use, high unattended throughput, and optical detection systems.

- ASTM D445, ASTM D446, ASTM 2270
- Automatic Unit
- Applicable for a wide range of samples
- 0.15 – 25,000 mm^2/s Measuring Range
- 8 – 16 mL Sample Volume
- 10 – 12 mL Solvent Consumption per Cycle
- 20 Measurements per Hour
- Ubbelohde Based Viscometer

- ASTM D445, ASTM D446, ASTM 2170
- Automatic Unit
- Applicable for high viscous samples
- 0.15 – 120,000 mm^2/s Measuring Range
- 12 mL Sample Volume
- 20 – 30 mL Solvent Consumption per Cycle
- 4 Measurements per Hour
- Ubbelohde Based Viscometer

- ASTM D7279, ASTM D2270
- Automatic Unit
- Applicable for a wide range of samples
- 0.3 – 3,000 mm^2/s Measuring Range
- 0.3 – 1.0 mL Sample Volume
- 2 – 3 mL Solvent Consumption per Cycle
- 80 Measurements per Hour
- Houillon Based Viscometer

ASTM D445 IMPROVEMENTS

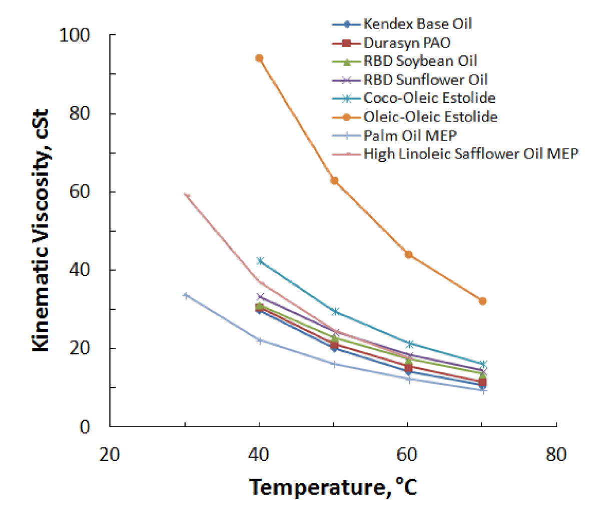
Due to the many factors that influences a fluid's viscosity, it is clear why there is an importance for viscosity measurement in our industry. In 1937, the method to determine the kinematic viscosity of transparent and opaque liquid petroleum products was defined by ASTM D445. As it was all these years back, the method measures the time required for a fixed volume of sample to pass through a calibrated viscometer at a controlled temperature. Dynamic viscosity can be calculated using this method as well, as long as the density of the sample is known. ASTM D445 is an essential method in our industry, and as a result, the method is constantly updated to maintain clarity and to make it easier to follow the procedure by engineers, scientists, and lab workers, and to improve its precision. ASTM D445 is the most common method used in our industry, since it covers such a wide range of samples.

Some changes to ASTM D445 recently revolve around aligning ASTM D445 with IP71. Differences between these methods include inconsistent precisions with samples of jet fuel at -20°C and with diesels, biofuels, and blends at 40°C. Also, the precision of the manual viscometry in ASTM D445 is under review, with a troubleshooting table to be added to the appendix. The table explains the causes to commonly observed errors, and provides a resolution to the observed error. Some common observed errors to be included in the troubleshooting guide are flow times not meeting the determinability of ASTM D445, short or long flow times, and poor repeatability with certified viscosity reference standards. A troubleshooting guide is beneficial to ASTM D445, since it allows operators to resolve these errors on their own, which would improve the accuracy and repeatability of their results.

COMPARATIVE ANALYSIS

Oil samples were provided by the United States Department of Agriculture. The samples were tested to determine their kinematic viscosity using the Omnitek U-VIsc 120. The unit operates under the guidelines in ASTM D445. This instrumentation automatically measures the flow time of the samples to pass through the viscometer tube. With the supplied tube constants, the unit also automatically determines the kinematic viscosity, if the test passes the determinability requirements of ASTM D445. Eight oil samples were tested for their kinematic viscosity across a range of temperature. The results for the kinematic viscosity (in units of cSt) at various temperatures for the eight oils are shown in the table and graph below.

Sample	40°C	50°C	60°C	70°C
Kendex Base Oil	29.88	20.22	14.37	10.65
Durasyn PAO	30.68	21.38	15.54	11.70
RBD Soybean Oil	31.32	23.02	17.74	13.76
RBD Sunflower Oil	33.44	24.43	18.49	14.43
Coco-Oleic Estolide	42.57	29.62	21.45	16.15
Oleic-Oleic Estolide	94.20	63.06	44.26	32.33
Palm Oil Methyl Ester Phosphonate	22.34	16.27	12.27	9.53
High Linoleic Safflower Oil Methyl Ester Phosphonate	37.04	24.81	17.79	X



The data expresses the theoretical relationship between kinematic viscosity and temperature, where the viscosity decreases exponentially with an increase in temperature. This relationship is clearly shown for each sample, and with only four temperatures. With this data, further analysis of the samples can be done. If the density is measured at each temperature, the dynamic viscosity can be calculated for each sample as a function of temperature. Then, the data can be fit with an Arrhenius model, to determine thermodynamic properties of the samples.

Additionally, this instrument is shown to be both versatile and reliable, as it is capable of determining reproducible results for a wide range of products. This comparative analysis is an example of how these new viscometry instruments, are top of the line instrumentation for viscosity testing, and will enable ASTM D445 and related specifications to improve its effectiveness.

CONCLUSIONS

ASTM D445 has been around for a long time, and is a critical test method in our industry. Therefore, it is a necessity to maintain a clear method. Inexperienced users who have yet to practice ASTM D445 should be able to follow the method as easily as experienced users who commonly use it. Advancements with viscometry instrumentation have further improved the viscosity testing industry. These instruments are easy to use, produce consistent results, and can test many samples per hour. The unit used for this poster, the Omnitek U-VIsc series, is one of the cutting edge instruments in our industry. This unit, along with other new instruments, are effective upgrades to the existing outdated instrumentation. With improvements made to viscometry instrumentation, ASTM D445 will benefit immensely with better accuracy and repeatability of results, more consistent flow times that meet the determinability, and a simply operability.

REFERENCES

- **ASTM D445-17a** "Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (Calculation of Dynamic Viscosity)" (West Conshohocken, PA: ASTM International)
- **ASTM D2170-10** "Standard Test Method for Kinematic Viscosity of Asphalts (Bitumens)" (West Conshohocken, PA: ASTM International)
- **ASTM D7279-08** "Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids by Automated Houillon Viscometer" (West Conshohocken, PA: ASTM International)
- **ASTM D8185-18** "Standard Guide for In-Service Lubricant Viscosity Measurement" (West Conshohocken, PA: ASTM International)

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