ASTM D7042: THE QUANTUM LEAP IN VISCOSITY TESTING TECHNOLOGY

Introduction

Viscosity is a critical quality-control parameter across many industries, particularly in petroleum, where it serves as a key indicator for products ranging from crude oil to refined outputs. Traditionally, the industry has relied on glass capillaries in line with the ASTM D445[1] standard to measure viscosity manually. This method, being gravity-dependent, primarily reports only kinematic viscosity rather than dynamic viscosity. In contrast, modern viscosity measurement techniques are independent of gravitational influence and measure dynamic viscosity directly. To facilitate comparisons to other methods, these modern methods also calculate kinematic viscosity by incorporating an additional density measurement, and dividing dynamic viscosity by the sample density.

$$v = \eta/\rho$$

v… kinematic viscosity
η… dynamic viscosity
ρ… density

SVM Series: Automatic ASTM D7042 Viscometers

In this article, we explore recent advancements in viscosity measurement techniques, which have evolved well beyond simply measuring multiple physical parameters simultaneously. We will also discuss why new viscosity testing methods have adopted measurement principles distinct from the traditional glass capillary technique. Using ASTM D7042,[2] the SVM test method, as an example, we'll highlight the benefits of these innovations for both individual users and the industry as a whole.

A shift from tradition to innovation

The ASTM D445 standard, a traditional method for determining kinematic viscosity, was first introduced in 1937, making it an over 80-year-old technique. Achieving accurate results with ASTM D445 typically requires a skilled operator who rigorously follows the detailed standard procedure, which has now over 15 pages. Among its many requirements, ASTM D445 mandates precise temperature control, allowing no more than a ±0.02 °C variation within the capillary bath, correct positioning of the capillary to within 1° (or even 0.3° for specific viscometers), establishing an appropriate equilibration time through trial, regular verification of timer accuracy, and ensuring a minimum flow time of 200 seconds.

Over recent decades, efforts have been made to modernize ASTM D445 by integrating automated procedures into what has historically been a manual method. Automated D445 systems are defined as apparatuses with one or more mechanized steps that retain the fundamental technique and principles of the manual method. To enhance measurement speed and broaden the viscosity range, a complex "kinetic energy correction" calculation was introduced. However, as ASTM D445 expanded to include automation, only a limited range of samples – including FAME, base oils, and formulated oils – were tested at only select temperatures to verify consistency with the manual method. Currently, there is no comprehensive assessment confirming that automated systems are unbiased for all sample types used in the petroleum industry, leaving this gap unaddressed.

Even with automation, several inherent limitations of the glass-capillary method persist. These include a restricted viscosity range for individual capillaries (typically 5 to 100-fold), the need for large volumes of volatile and potentially toxic bath liquids (typically 1 L to 5 L), extended temperature equilibration times (30 minutes recommended), significant solvent (40 mL to 100 mL) and sample volume (12 mL to 13 mL), as well as considerable energy usage (1,000 W and more per bath). Moreover, despite the degree of automation, a D445 viscometer only measures a single parameter, kinematic viscosity, limiting its application in multiparametric analyses.

Due to these drawbacks - and to meet modern-day industry demands with respect to economic and environmental expectations, and safety requirements - instrument manufacturers have developed more contemporary automated techniques. Those methodologies, like ASTM D7042, follow

SVM 3001: Maximum Flexibility - Multiple Parameters and Widest Temperature Range

a novel measuring principle, capable of determining dynamic viscosity, density and thus kinematic viscosity, with up to a tenfold decrease in volumes of sample and solvent, rapid thermoelectric heating and cooling with a wide accessible temperature range, as well as a measuring cell that covers the entire viscosity range relevant to the petroleum industry.

Direct measurement of kinematic viscosity: Only a myth

As previously noted, modern techniques determine kinematic viscosity indirectly, deriving it from separate measurements of dynamic viscosity and density. However, no single technique exists that can directly measure kinematic viscosity. In traditional glass capillary methods, the primary parameter measured is the sample's flow time, which must then be multiplied by a calibration constant, individually determined for every single capillary, to yield the kinematic viscosity:

$$v=C*t$$

v = kinematic viscosity

C = calibration constant

t = time

Furthermore, the calibration constant itself is influenced by the local gravitational acceleration (g) at the site of calibration. If the gravitational acceleration at the measurement location differs from that at the calibration site by more than only 0.1 %, an adjustment to the calibration constant is required to ensure accuracy.

Multi-talent powerhouse

ASTM D7042, the SVM method, provides more than just a single parameter with the push of a button. In addition to the

SVM 4001: With Two Cells: Measure Simultaneously at Two Different Temperatures

standard dynamic viscosity and density measurements, it can determine a wide range of derived parameters, all fully compliant with ASTM standards. For example, the method offers the flexibility to simultaneously measure viscosity at both 40 °C and 100 °C. According to ASTM D2270,[3] these values can then be used to calculate the viscosity index (VI). Another feature of D7042-compliant instruments is the determination of the viscosity gravity constant (VCG) in accordance with ASTM D2501,[4] or the mean molecular mass (M) following ASTM D2502,[5] both of which accept D7042 results as input values.

Moreover, using these parameters alongside refractive index measurements, D7042 viscometers can calculate the carbon type composition (CTC) in compliance with ASTM D2140,[6] or determine the carbon distribution and ring content according to ASTM D3238.[7] These built-in calculation capabilities significantly enhance the practical applicability of D7042 viscometers, offering a more comprehensive analysis in a single, automated process.

Unmatched simplicity

ASTM D7042 is designed to accommodate a wide range of sample introduction methods, from manual handling to fully automated systems, which may even include pre-heating capabilities. The latest iteration of D7042 viscometers has taken sample introduction to the next level of simplicity. These instruments are equipped with a funnel, allowing the operator to directly pour the sample into the device – eliminating the need to transfer the sample into a vial, using a pipette or syringe beforehand. With just the push of a button, the sample is automatically filled, measured in full compliance with D7042, and drained, all without requiring any further user intervention.

SVM 1001 Simple Fill: The Budget-Friendly Choice for Measuring Kinematic Viscosity

Maximum flexibility

The measurement principle outlined in ASTM D7042 offers remarkable flexibility. Its integrated thermoelectric temperature control, coupled with compact low-volume measuring cells, enables instruments to achieve rapid and automatic thermal equilibration of the sample as well as heating and cooling rates of up to 20 °C per minute. Together, these features provide significant advantages over the conventional glass capillary method by enabling a broader range of sample analysis, from jet fuel

(-40 °C) to wax (+135 °C) in one instrument. Fully automated temperature scans can be performed to study the temperature dependence of samples. Additionally, unlike the glass capillary method, which measures viscosity at discrete points, the continuous nature of the viscosity measurement in ASTM D7042 allows for real-time monitoring of viscosity changes over time via a time scan.

Precision without compromise

Every standardized test method must include an evaluation of its precision. The D7042 standard provides a comprehensive performance assessment, entirely conducted by ASTM, across a wide range of sample types and temperatures relevant to the petroleum industry. These samples include base oils, formulated oils, diesel and biodiesel fuels, jet fuels, and residual fuel oils. During the development of the method, multiple laboratories worldwide measured several samples of each type using both the D7042 and the D445 method for comparison. For each sample type, a detailed research report was published, outlining the precision of both methods. Table 1 lists examples extracted from these reports.

Table 1: Precision of D7042 vs D445

Base Oils at 40 °C[8]	**D7042**	**D445**
Instrument	Anton Paar SVM	Glass capillary
Repeatability r(95)	0.09 %	0.25 %
Reproducibility R(95)	0.58 %	0.79 %
Jet fuels at -20 °C[9]	**D7042**	**D445**
Instrument	Anton Paar SVM	Glass capillary
Repeatability r(95)*	1.07 %	1.24 %
Reproducibility R(95)*	1.86 %	2.18 %
Formulated oils at 40 °C[10]	**D7042**	**D445**
Instrument	Anton Paar SVM	Glass capillary
Repeatability r(95)**	0.64 %	1.07 %
Reproducibility R(95)**	1.16 %	1.90 %

* at 7.98 mm^2/s

** at 150.7 mm^2/s

In a nutshell, in all of the listed studies, the performance of D7042 was found to be equal or even better than the same sample set measured in accordance to D445.

Studies conducted by ASTM have also provided statistical insights into potential systematic deviations, or biases, between test methods D445 and D7042. Such biases have been identified for certain sample types and temperatures. Conveniently, the statistical analysis yielded formulas that allow users to convert D7042 results to D445, producing values that can be considered practically equivalent to those from the traditional method.

These bias formulas are integrated into D7042-compliant viscometers, enabling automatic calculations and removing the need for users to perform manual conversions. This built-in functionality streamlines the process, making it easier for operators to obtain results that correspond reliably to D445 measurements.

Versatility in key specifications

In the past 20 years of its existence, ASTM D7042 has become an established test method widely recognized across critical petroleum specifications, including D975[11] and EN 590[12] for distillate and diesel fuels, SAE J300[13] and D6074[14] for lubricants, ASTM D396[15] for fuel oils, D6158[16] and D8029[17] for hydraulic oils, and D3699[18] for kerosene, among others. In the aviation industry, the method is also fully compatible with standards like ASTM D1655[19] for aviation turbine fuels, ASTM D7566[20] for aviation fuels containing synthesized hydrocarbons, as well as JIG AFQRJOS[21] and Def Stan 91-091.[22]

As mentioned, one of the key advantages of the D7042 method is its dual capability to measure both viscosity and density, making it exceptionally versatile. This dual functionality aligns with specifications that require density as a parameter, enabling simultaneous certification of both viscosity and density. For modern instruments, this versatility extends to full compliance with ASTM D4052,[23] further enhancing their applicability across the latest petroleum industry standards.

Reduced maintenance

A key advantage of the D7042 measurement principle is its single measuring cell, which spans the entire viscosity range. This eliminates the need for tracking multiple glass capillaries in a quality management (QM) system. Additionally, D7042 viscometers are factory-calibrated across a broad temperature and viscosity range. As with any analytical technique, adhering to good laboratory practices is essential. It is recommended that reference materials be periodically measured to ensure optimal instrument performance, a process commonly referred to as calibration. This procedure does not alter the instrument's constants. Adjustments to these constants are only necessary when significant deviations from the reference material are detected. Such adjustments can be fully automated in modern instruments, ensuring ease of operation and accuracy.

In contrast, maintaining accuracy with glass capillary viscometers, as specified by ASTM D445, is far more complex and requires frequent checks of both timing devices and bath thermometers as specified by D445 at regular intervals. And although D445 does not regulate the frequency of viscosity tube calibration, many manufacturers of automated equipment indeed mandate recalibration, particularly when operating at a new temperature.

SVM 2001: Viscosity, Density, and More at a Range of Temperatures

The future of viscosity testing is here

In conclusion, ASTM D7042 represents a significant advancement in viscosity testing technology, offering a modern alternative to the traditional ASTM D445 glass capillary method. By directly measuring dynamic viscosity and density, D7042 provides an efficient, accurate, and versatile approach for determining kinematic viscosity – addressing many of the operational limitations and resource demands of the D445 method. The automated D7042 technique simplifies sample handling, reduces the required quantities of sample and solvent, and shortens temperature equilibration times, while covering the entire viscosity range with a single cell.

The D7042 standard is compliant with an extensive list of industry specifications and also offers enhanced multiparametric capabilities. In addition to providing density and viscosity information, D7042 viscometers can calculate additional values such as the viscosity index, molecular mass, and carbon type composition, adding depth to petroleum analysis. Furthermore, built-in ASTM bias formulas ensure that D7042 measurements are practically equivalent to D445, increasing confidence in cross-method comparisons without manual calculations.

The precision and reliability of ASTM D7042, coupled with its reduced maintenance requirements, make it a valuable tool for quality control in the petroleum industry and beyond. This innovative approach aligns with modern demands for accuracy, sustainability, and operational efficiency, providing industries with a contemporary solution for viscosity testing.

SVM 1001 Simple Fill: Simply Kinematic Viscosity - No Syringe Needed

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