CANNON GRAVITY GLASS CAPILLARY VISCOMETERS - the direct route to Kinematic Viscosity saves you time and reduces uncertainty

Kinematic viscometers have historically been the gravity glass capillary type as specified in ASTM D446 and directly measure kinematic viscosity (KV) following the ASTM D445 Test Method. Another approach to KV has been introduced as ASTM Test Method D7042 (Stabinger Viscometer). While the vendor of this technique claims their viscometer is equivalent to glass capillary it is in fact very different. The purpose of this paper is to explain these differences and the impact on your laboratory.

How KV is determined on both instruments:

The Cannon gravity glass capillary viscometer directly measures KV viscosity by the simple equation found in ASTM method D446, section 7.1.2:

$$v = C \times t$$

where v = kinematic viscosity (KV); C = an unchanging constant based on the dimensions of the glass capillary, and t = time for a fixed volume of the fluid to fall through the capillary.

In this method, the force due to gravity is constant and pulls the fluid down through the capillary as the drop time is measured by automatic sensors. This is, by far, the most simple and direct way to measure kinematic viscosity because it takes advantage of the constant force of gravity.

By comparison, kinematic viscosity calculations by the Stabinger viscometer are not shown in its test method (D7042). In section 3.1.3 a general relationship is shown to be

$$v = \frac{\eta}{\rho}$$

where v = kinematic viscosity; η = dynamic viscosity, and ρ = density. However, the method never explains how the numerator, the dynamic viscosity, is calculated. It is not clear why the vendor did not include the equations that govern the measurement of dynamic viscosity when they authored method D7042 in the mid-1990's. An [1]online search of how the Stabinger viscometer calculates dynamic viscosity (η) is shown below. Note that it is based off of a rotational viscometer design; not a gravity-based glass capillary.

For speed equilibrium, the driving torque of the rotor must equal its retarding torque.

$$M_D = M_R$$

$$M_D = K_1 \cdot \eta \cdot (n_2 - n_1)$$

$$M_R = K_2 \cdot n_1$$

$$\eta = \frac{K}{\frac{n_2}{n_1} - 1} = \frac{K}{\frac{n_2 - n_1}{n_1}} \rightarrow K = \frac{K_2}{K_1}$$

MD ... driving torque of the rotor
MR ... retarding torque of the rotor
n1 ... rotor speed
n2 ... tube speed
K1, K2, K ... constants; K is determined during adjustment

Equations 7 to 10: Equilibrium between driving torque (related to viscosity) and retarding torque (electromagnetic forces).

It is noteworthy that the two constants in this equation are not defined so one is left wondering what they mean or represent. In addition, they are not actually determined individually. If the individual values of the constants have physical significance beyond their ratio, then determining them only as a ratio may not be sufficient. It is also not clear how motor torque or speed variations are accounted for in this equation.

Furthermore, the physics behind the assumptions in the derivation might need to be considered. First, driving torque = retarding torque. We are asked to believe that this is true during the calibration and the subsequent measurements. Second, the driving torque is directly proportional to only the shear viscosity multiplied by the difference in the two speeds. Third, the retarding torque is directly proportional to only the rotor speed.

Lastly, there are influences that do not seem to be accounted for: Temperature dependence of inducted eddy currents; Secondary flows in the tube-rotor gap; Temperature gradients in the gap; Heat build-up in the sample while waiting to achieve steady-state flow equilibrium (the sample is sheared by the rotor at thousands of RPMs).

This is a short list of reasons why these assumptions used in the derivation may not be strictly true. The overall point is that the Stabinger viscometer does not explain how dynamic viscosity is determined (and hence kinematic viscosity) and uses many assumptions. Compare the overly complex Stabinger equation above, and all its assumptions, against the simplicity of $v = C \times t$ for the Cannon glass capillary.

To say that both of these instruments are measuring the same thing is like saying a straight highway and curved backroad with dangerous switchbacks get you to the same place.

The most obvious way to know that the Stabinger viscometer is overly complicated and does not produce results that are equivalent to the Cannon glass can be found in the Stabinger method D7042, table 4. It shows that seven out of the eight most common petroleum products must be bias corrected to be equivalent to the results from the Cannon viscometer.

What is the effect of a direct vs. indirect approach to KV?

The result of a convoluted approach to KV means more work and uncertainty for the laboratory. The ASTM method D7042, section 9.1, explains *"The recommended interval for viscosity and density calibration is once a month…For the calibration procedure follow the instructions of the manufacturer of the apparatus"*. By comparison with the Cannon glass capillary, methods D445/D446 do not require periodic re-calibration. This translates to less work for the laboratory.

The workload for the Stabinger user is further increased if they abide by the instrument's Instruction Manual In section 7, table 3, it tells the operator to verify calibration *"regularly, preferably daily or at least before starting a measurement series"*. In addition, it recommends calibration *"once a week to once a month and before starting important measurements"*. As compared to the simple Cannon glass capillary, the Stabinger user bears the burden of increased verifications and calibrations because of the instrument complexity.

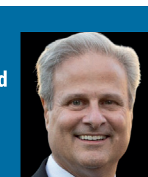
Continuing in section 10.1 to 10.3 in the Stabinger ASTM method D7042… *"An adjustment has to be carried out when repeated calibration check measurements do not agree with the Acceptable Tolerance Band as stated in 9.4 and the error cannot be located elsewhere. For the adjustment procedure follow the instructions of the manufacturer of the apparatus…After an adjustment procedure a calibration check measurement shall be performed."* None of these adjustments exist in the Cannon glass capillary D445 method…the extra work required of the Stabinger is stark.

Conclusion

The Stabinger user must constantly verify, calibrate, and adjust the instrument because the apparatus is overly complicated as compared to fluid flowing through a capillary under the influence of gravity. As a result, the Stabinger user is less productive and carries the constant burden of not knowing if the instrument is properly tuned for their particular sample. By contrast, the Cannon viscometer user simply pushes a button, gravity does its work, and time is automatically measured. To unburden your viscosity measurements, contact Cannon at www.cannoninstrument.com.

Author Contact Details

Don DiPietro is VP of Product Management and Applications for Cannon Instrument Company



Don DiPietro has a B.S. degree in Mechanical Engineering and 38 years of working experience in the viscosity and rheology measurement business.

- Tel: 800-676-6232
- Email: sales@cannoninstrument.com
- **www.cannoninstrument.com**

Footnotes:
• ASTM methods references in this paper can be obtained at astm.org.
Sources:[1] https://wiki.anton-paar.com/us-en/how-to-measure-viscosity/