CANNON INSTRUMENT COMPANY

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Tech Brief 101

Calculation of Viscometer Constants for Cannon-Fenske Routine and Cannon-Fenske Opaque Viscometers

Certain modified Ostwald-type viscometers for transparent liquids (like the Cannon-Fenske Routine and the Cannon-Manning Semi-Micro) and reverse-flow viscometers for opaque and transparent liquids (like the Cannon-Fenske Opaque) are always filled with a precise volume of test sample. Because filling is normally done at ambient temperature and the kinematic viscosity is most often measured at another temperature, the volume of the test sample in these viscometers increases or decreases slightly as the temperature rises or falls. This volume change causes a change in the driving head of the liquid during measurement of the flow time. Since the driving head is one of the factors determining the viscometer constant, measurement of viscosity at a temperature different from the calibration temperature will require a different viscometer constant.

By using equations printed in ASTM D 446, the viscometer constants of Cannon-Fenske Routine and Cannon-Fenske Opaque viscometers can be calculated at temperatures other than those at which the viscometers were calibrated. For example, data from the calibration of such a viscometer at 40°C will permit the calculation of the viscometer constant at 100°C. In fact, we recommend that glass capillary kinematic viscometers be calibrated at 25°C or 40°C, but not at 100°C. An additional viscometer constant at 100°C can be calculated more accurately from the 25°C or 40°C calibration than it can be measured at 100°C. Please refer to ASTM D 446 for details of the method described below. **Important:** If you are using Cannon-Fenske Routine viscometers as described in ASTM D 789, calibration must be done at 25°C using 10 mL of a standard pipetted into the viscometer.

For a **Cannon-Fenske Routine** viscometer, the following equation permits calculation of the viscometer constant *C* at any temperature from a viscometer constant determined experimentally at another temperature.

$$C = C_0 (1 - B [T_t - T_f])$$

For a **Cannon-Fenske Opaque** viscometer, the following equation is used to obtain the viscometer constant *C*.

$$C \quad C_0 (1 + B\,[\,T_t - T_f\,])$$

Please note that the two equations are identical except for the sign before *B*. In these equations,

C_0 = the viscometer constant when filled and tested at the same temperature
T = temperature, °C
B = the temperature dependence factor
t, f subscripts = values at the test temperature and at the fill temperature, respectively.

The temperature dependence factor *B* printed on our calibration certificates assumes a value for the coefficient of thermal expansion typical of mineral oil and the measured instrument dimensions printed on the certificate of calibration. Therefore, if you are measuring the kinematic viscosity of mineral oils you can easily calculate the viscometer constant *C* at an additional temperature if you know the constant C_0. Conversely, if you have measured the viscometer constant *C* at a given temperature, by use of the above equations you can calculate the value of C_0. From the new value of C_0 you can then calculate the value of *C* at additional temperatures.

If you are measuring the kinematic viscosity of liquids other than mineral oils, the following equation permits the calculation of the temperature dependence factor for the liquid:

$$B \quad 4\,V\,(\rho_f - \rho_t)\;/\;\pi\,d^2\,h\,\rho_t\,(T_t - T_f)$$

where
V = volume of charge, cm^3
d = average diameter, cm, of the meniscus in the upper reservoir
h = average driving head, cm
ρ = density, g/cm^3, and
t, f subscripts = as defined for the previous equation.

On every Cannon calibration certificate for a Cannon-Fenske Routine or Opaque viscometer the values for *V*, *d*, and *h* are given. These values were measured by Cannon and should not change. They can therefore be plugged directly into the above equation. The density of the liquid at the fill temperature and at the test temperature must be determined. A pycnometer method is recommended.

Sample Calculation for a Cannon-Fenske Routine Viscometer

A typical calculation, using data from a calibration certificate for a size 450 Cannon-Fenske Routine viscometer, is given here. The certificate itself is included at the end of this article. First C_0 is calculated from the actual value of *C* determined by calibrating the viscometer at 40°C. Cannon determines the viscometer constants using two different standards, then takes the average of the two constants. One standard is normally sufficient whenever a user recalibrates his or her viscometer. In this particular case, a constant of 2.540 mm^2/s^2 was found.

The value of B for this viscometer is 81 x $10^{-6}/°C$. The room temperature (filling temperature) was 23°C. Plugging these values into the equation for the Cannon-Fenske Routine, we obtain the following:

$$2.540 = C_0[1 - ((81 \times 10^{-6})\ (40 - 23))]$$

When this equation is solved, C_0 proves to be 2.544.

The calibration constant for the viscometer at 100°C can now be calculated using the same equation.

$$C_{100} = 2.544[1 - ((81 \times 10^{-6})\ (100 - 23))]$$

When this equation is solved, C_{100} for bulb C turns out to be 2.528.

Sample Calculation for a Cannon-Fenske Opaque Viscometer

A typical calculation, using data from a calibration certificate for a size 100 Cannon-Fenske Opaque viscometer, is given here. The certificate itself is included at the end of this article. First C_0 is calculated from the actual value of C determined by calibrating the viscometer at 40°C. Cannon determines the viscometer constants using two different standards, then takes the average of the two constants. One standard is normally sufficient whenever a user recalibrates his or her viscometer. In this particular case, a constant of 0.01446 mm^2/s^2 was found for bulb C. The value of B for bulb C of this viscometer is 121 x $10^{-6}/°C$. The room temperature (filling temperature) was 23°C. Plugging these values into the equation for the Cannon-Fenske Opaque, we obtain the following:

$$0.01446 = C_0[1 + ((121 \times 10^{-6})\ (40 - 23))]$$

When this equation is solved, C_0 proves to be 0.01443.

The calibration constant for the viscometer at 100°C can now be calculated using the same equation.

$$C_{100} = 0.01443[1 + ((121 \times 10^{-6})\ (100 - 23))]$$

When this equation is solved, C_{100} for bulb C turns out to be 0.01456. The value of C_{100} for bulb D is calculated in the same manner.

Certificate of Calibration

Viscometer No. 450 A000

Sample

CANNON-FENSKE ROUTINE TYPE FOR TRANSPARENT LIQUIDS

(Standard Test ASTM D 445, IP 71 and ISO 3104)

Constant at 40°C	2.540	mm^2/s^2, (cSt/s)
Constant at 100°C	2.528	mm^2/s^2, (cSt/s)

The viscometer constant at other temperatures can be obtained by interpolation or extrapolation. To obtain kinematic viscosity in mm^2/s(cSt) multiply the efflux time in seconds by the viscometer constant. To obtain viscosity in mPa·s (cP) multiply the kinematic viscosity in mm^2/s(cSt) by the density in grams per milliliter.

The above constants assume a value for the coefficient of thermal expansion typical to that for mineral oil, and that the viscometer was filled with test sample at room temperature. If the filling temperature T_F is substantially different than room temperature, the viscometer constant at test temperature T_T is $C_o (1 - B [T_T - T_F])$. The values of C_o and B shown below are based on a coefficient of thermal expansion typical to that for a mineral oil.

Kinematic viscosities of the standards used in calibrating were established in Master Viscometers as described in Ind. Eng. Chem. Anal. Ed. 16,708(1944), ASTM D 2162, and the Journal of Research of the National Bureau of Standards, Vol. 52, No. 3, March 1954, Research Paper 2479.

Kinematic viscosities are based on the value for water adopted by the National Institute for Standards and Technology and The American Society for Testing Materials July 1, 1953. The kinematic viscosity basis is 1.0038 mm^2/s(cSt) for water at 20°C (ITS-90). The gravitational constant, g, is 980.1 cm/sec^2 at the Cannon Instrument Company. The gravitational constant varies up to 0.1% in the United States. To make this small correction in the viscometer constant, multiply the above viscometer constant by the factor [g(at your laboratory) /980.1]. The calibration data below are traceable to the National Institute for Standards and Technology. Temperature measurement traceable to NIST (Test No. 246089).

CALIBRATION DATA AT 40°C

Viscosity Standard	Kinematic Viscosity mm^2/s, (cSt)	Efflux Time Seconds	Constant mm^2/s^2, (cSt/s)
9314	654.5	257.68	2.540
9315	1011.6	398.15	2.541

Room Temp. (approx.) 23 °C. — Average = 2.540

Charge (approx.) 7.2 ml. — C_o = 2.544

Driving fluid head (approx.) 9.3 cm. — B = 81 $\times 10^{-6}$/°C

Working diameter of lower reservoir 3.0 cm.

Constant at 100° C. is 0.49 % lower than the constant at 40° C.

Calibrated by under supervision of ____________________

Please note: This calibration remains valid for 10 years unless (1) the viscometer has been damaged or (2) materials which chemically attack borosilicate glass (e.g., hydrofluoric acid or highly alkaline solutions) have been used. Nonetheless, it is recommended that the calibration be verified with kinematic viscosity standards periodically; if a change in calibration is indicated, carefully examine all sources of error, including especially temperature measurement since most apparent changes in calibration of the viscometer are due to errors in temperature measurement.

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The S.I. unit of kinematic viscosity is 1 meter squared per second, and is equal to 10^4 stokes. The S.I. unit of viscosity is 1 pascal second, and is equal to 10 poises. One centistokes is equal to one millimeter squared per second.

Certificate of Calibration

Sample

Viscometer No. 100 A000

CANNON-FENSKE (REVERSE FLOW) TYPE FOR OPAQUE LIQUIDS
(Standard Test ASTM D 445 and 3104)

	Constant, mm^2/s^2, (cSt/s) C	Constant, mm^2/s^2, (cSt/s) D
Viscometer Constant at 40°C	0.01446	0.01055
Viscometer Constant at 100°C	0.01456	0.01065

The viscometer constant at other temperatures can be obtained by interpolation or extrapolation. To obtain kinematic viscosity in mm^2/s (cSt) multiply the efflux time in seconds by the viscometer constant. To obtain viscosity in mPa·s (cP) multiply the kinematic viscosity in mm^2/s (cSt) by the density in grams per milliliter.

The above constants assume a value for the coefficient of thermal expansion typical to that for mineral oil, and that the viscometer was filled with test sample at room temperature. If the filling temperature T_F is substantially different than room temperature, the viscometer constant at test temperature T_T is C_o (1 + B [T_T - T_F]). The values of C_o and B shown below are based on a coefficient of thermal expansion typical to that for a mineral oil.

Kinematic viscosities of the standards used in calibrating were established in Master Viscometers as described in Ind. Eng. Chem. Anal. Ed. 16, 708(1944), ASTM D2162, and the Journal of Research of the National Bureau of Standards, Vol. 52, No. 3, March 1954, Research Paper 2479.

Kinematic viscosities are based on the value for water adopted by the National Bureau of Standards and The American Society for Testing Materials July 1, 1953. The viscosity basis is 1.0038 mm^2/s (cSt) for water at 20°C (ITS-90). The gravitational constant, g, is 980.1 cm/sec^2 at the Cannon Instrument Company. The gravitational constant varies up to 0.1% in the United States. To make this small correction in the viscometer constant, multiply the above viscometer constant by the factor [g(at your laboratory) /980.1]. The calibration data below are traceable to the National Institute for Standards and Technology. Temperature measurement traceable to NIST (Test No. 246089)

CALIBRATION DATA AT 40°C

Viscosity Standard	Kinematic Viscosity mm^2/s, (cSt)	Efflux time, Seconds C	Efflux time, Seconds D	Constant, mm^2/s^2, (cSt/s) C	Constant, mm^2/s^2, (cSt/s) D
9205	3.287	227.38	311.57	0.01446	0.01055
9206	6.146	425.06	582.06	0.01446	0.01056

Room Temp. (approx.) 23 °C. Average = 0.01446 0.01055

Charge (approx.) 12.4 mL. C_o = 0.01443 0.01053

Driving fluid head (approx.) 15.5 cm for C, 11.2 cm for D. B = 121 x 10^{-6}/°C, 145 x 10^{-6}/°C

Working diameter of upper reservoir 2.5 cm for C, 2.7 cm for D.

Constant at 100° C. is 0.73 % for C, 0.87 % for D higher than at 40° C.

Calibrated by under supervision of

Please note: This calibration remains valid for 10 years unless (1) the viscometer has been damaged or (2) materials which chemically attack borosilicate glass (e.g., hydrofluoric acid or highly alkaline solutions) have been used. Nonetheless, it is recommended that the calibration be verified with kinematic viscosity standards periodically; if a change in calibration is indicated, carefully examine all sources of error, including especially temperature measurement since most apparent changes in calibration of the viscometer are due to errors in temperature measurement.

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