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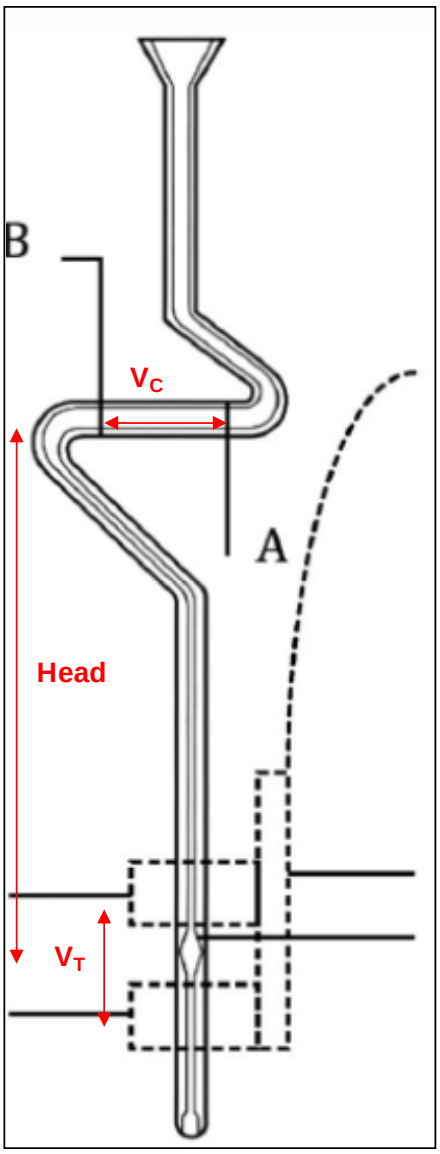
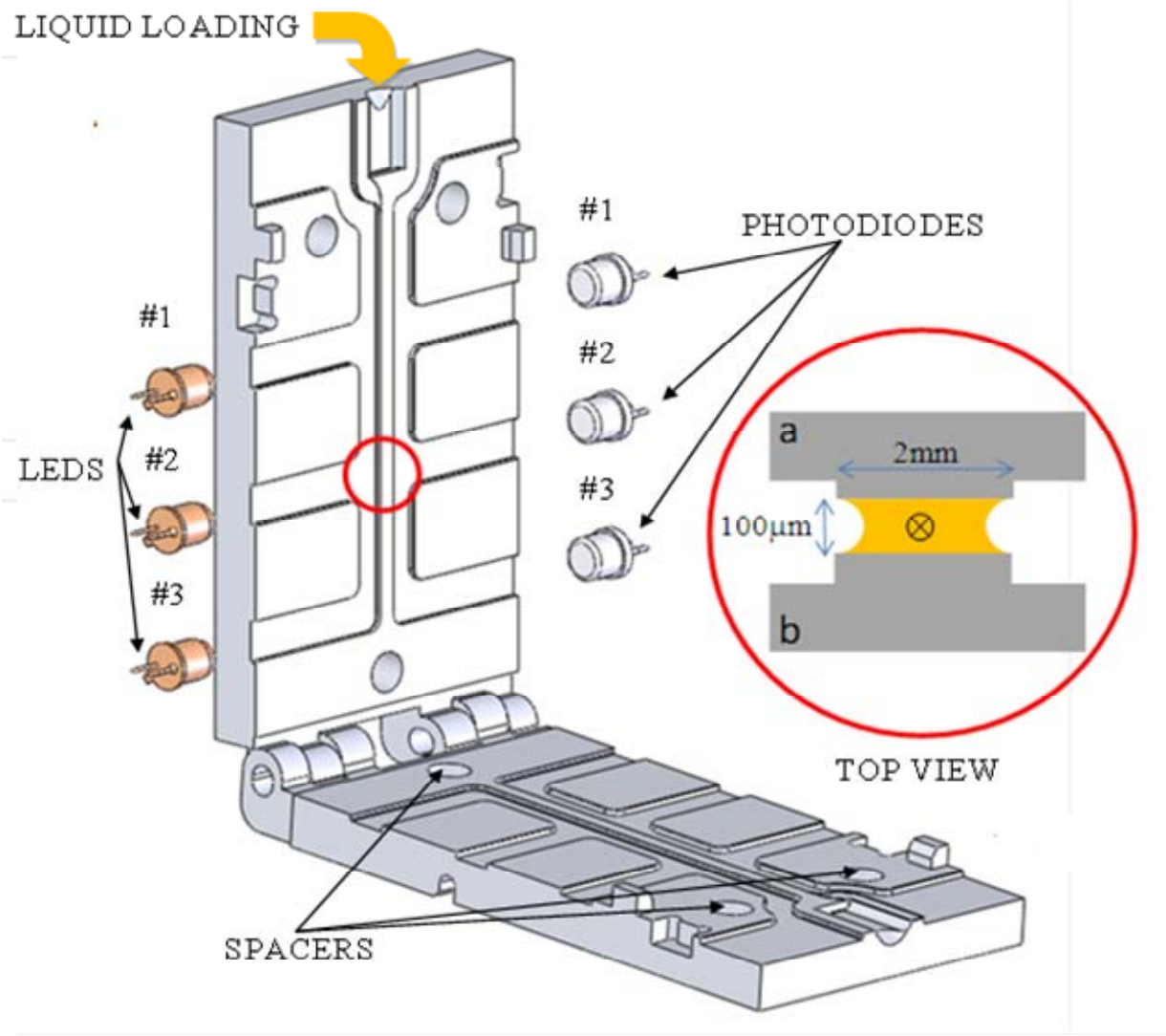
Overview

An analysis was conducted to compare the operational characteristics of two different bench-top semi-automated viscometers – the Cannon SImpleVIS and the Spectro Q3000. This analysis looked at three key areas which can lead to errant viscosity measurements when utilizing a capillary viscometer where gravity is the motivating force for the measurement. These errors can range in magnitude from imperceptible (in the noise of the instrument precision) to serious measurement inaccuracies.

Diagrams of Viscometer Capillaries



Cannon SimpleVIS Viscometer Tube – Fixtured Borosilicate Glass in Aluminum Block



Spectro Q3000 Viscometer – Removable Aluminum Capillary Cell

Operational Faults Studied in this Analysis

- Angular misalignment of the viscometer off the vertical axis
- Temperature inaccuracy of the viscometer and sample
- Contamination or occlusion of the capillary changing the effective diameter
- Sample charge volume inaccuracies

All gravity-flow capillary viscometers are governed by the Hagen-Poiseuille equation:

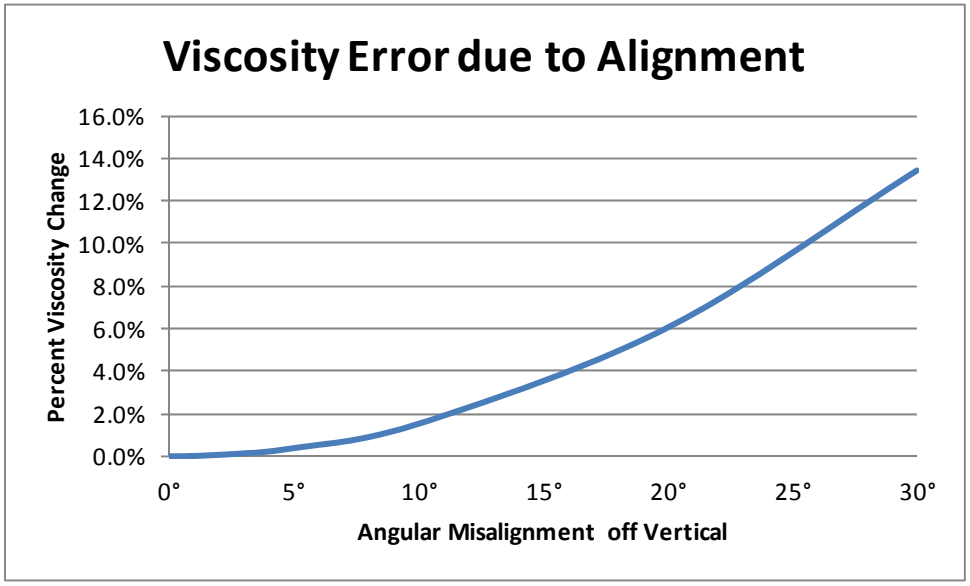
$$KV(\nu) = \Pi * H*g*r^4*t / (8*L*V) = c * t \quad (mm^2/s)$$

r = radius of the capillary (mm)
L = effective working length of the capillary (mm)
H = average driving head of fluid, midway between timing marks (mm)
g = gravitational acceleration constant (980.24 cm/s^2)
V = volume between start and stop timing marks (mL)

Angular misalignment of the viscometer off the vertical axis

All capillary viscometers are affected, regardless of the length (L) of the capillary and its associated driving head (H), by the angular alignment differences between how it was calibrated and subsequently operated after calibration. The tables below illustrate how severe this angular misalignment can affect the viscosity measurement. Less than 10 degrees tilt can be considered acceptable for bench-top measurements where precision of less than 2% is accepted. Tilt larger than 10 degrees can lead to serious errors.

	Driving Head	Driving Head due to Angular Alignment off Vertical						
	mm	0°	1°	3°	5°	10°	20°	30°
SimpleVIS	88.2	88.20	88.19	88.08	87.86	86.86	82.88	76.38
Q3000	30.0	30.00	30.00	29.96	29.89	29.54	28.19	25.98
	Viscosity Range	Percent Viscosity Error due to Angular Alignment off Vertical						
	mm^2/s	0°	1°	3°	5°	10°	20°	30°
SimpleVIS	10-700	0.00%	0.02%	0.14%	0.38%	1.52%	6.03%	13.40%
Q3000*	10-350	0.00%	0.02%	0.14%	0.38%	1.52%	6.03%	13.40%
	* note Q3000 angular alignment error is above is only in one axis. Error increases greatly							
	when in the other axis (left/right) due to sample running out of unconfined flow channel							



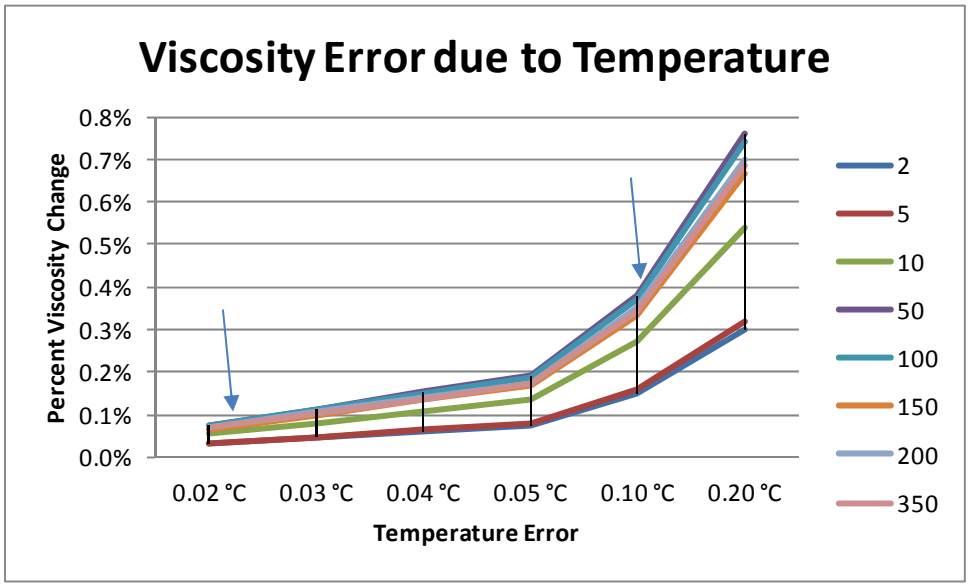
A key point in the error shown above with the Q3000 viscometer, which utilizes an unbounded (open on two sides) microchannel capillary (Hele-Shaw flow cell) which is 100 microns by 2 millimeters in dimension, is only valid in one alignment - front to back. The error associated from misalignment towards the unbounded sides of the capillary (left to right) can be quite severe if the surface tension of the fluid (or lack thereof due to surface contaminates on the capillary cell walls) allow sample to "leak" out of the flow cell. This error can only be determined experimentally and is not shown in the tables or chart.

Temperature Inaccuracies

Temperature directly affects the viscosity of most samples and in particular petroleum-based samples where the temperature-viscosity relationship is quite strong. In many cases the viscosity of petroleum-based lubricating oils decreases approximately 20% for every 5 degree increase in temperature. As a consequence, having tight thermal regulation of the viscometer and the sample under test is paramount to precise viscosity measurements.

Nominal Viscosity	Viscosity Change	Percent Viscosity Error due to Temperature Error					
mm^2/s	$mm^2/s/°C$	**0.02 °C**	0.03 °C	0.04 °C	0.05 °C	**0.10 °C**	0.20 °C
2	0.03	0.030%	0.045%	0.060%	0.075%	0.150%	0.300%
5	0.08	0.032%	0.048%	0.064%	0.080%	0.160%	0.320%
10	0.27	0.054%	0.081%	0.108%	0.135%	0.270%	0.540%
50	1.90	0.076%	0.114%	0.152%	0.190%	0.380%	0.760%
100	3.70	0.074%	0.111%	0.148%	0.185%	0.370%	0.740%
150	5.00	0.067%	0.100%	0.133%	0.167%	0.333%	0.667%
200	7.00	0.070%	0.105%	0.140%	0.175%	0.350%	0.700%
350	12.00	0.069%	0.103%	0.137%	0.171%	0.343%	0.686%

Note: SimpleVIS temperature control accuracy at +/-0.02 °C and Q3000 accuracy at +/-0.1°C

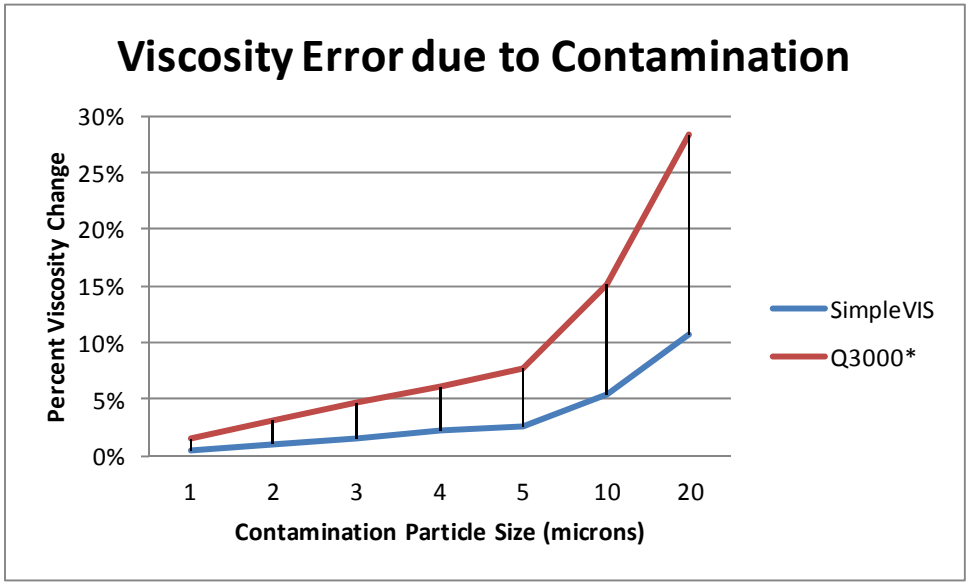


Contamination or Occlusion of the Capillary

The influence of the capillary radius is the most significant contributor (raised to the fourth power) in the Hagen-Poiseuille equation. Contamination or occlusion of the capillary will result in a decrease of the effective capillary diameter leading to a large measurement error. This contamination can come from a foreign particle in the sample which may become lodged or adhered to the capillary wall or from improper cleaning of the viscometer - such as from lint or dust. The smaller the capillary diameter, the more pronounced the error from contamination as a function of the contaminate size.

	Capillary Diameter	Percent Error Due to Contamination or Occlusion in the Capillary						
	mm	1 micron	2 micron	3 micron	4 micron	5 micron	10 micron	20 micron
SimpleVIS	0.72	0.5%	1.1%	1.6%	2.2%	2.7%	5.4%	10.7%
Q3000*	0.25	1.6%	3.2%	4.7%	6.2%	7.8%	15.1%	28.4%
	Note: Q3000 is a non-conventional rectangular capillary channel unbounded on the sides							
	with an effective diameter of 0.2523 mm.							

Proper cleaning of the viscometer is critical to maintaining accurate measurements. In instruments such as the Q3000, the capillary can easily be scratched by the wiping cloth which can trap small particles and allow them to be dragged across the polished capillary surfaces. Additionally, contaminates such as lint, dust, hair, or fibers can easily be left on the capillary surface and serve to occlude the flow of subsequent samples being tested.



Sample Charge Volume Inaccuracies

The sample charge volume (V) is critical to accurate measurements as it also affects the driving head (H) of the fluid in the capillary. The SimpleVIS operates with a 500 µL (0.5 mL) sample charge volume while the Q3000 operates with a 60 µL (0.06 mL) sample charge volume. The Q3000 is an order of magnitude more sensitive to small errors in sample volume. The SimpleVIS viscometer system is provided with a ultra-precise positive-displacement laboratory style pipettor in which the charge volume is not affected by the sample viscosity. This positive-displacement pipette ensures consistent 500 µL sample charge volumes regardless of whether low-viscosity fuel (3 cSt) or high-viscosity gear oil (680 cSt) is being drawn for testing. In contrast, the Q3000 is supplied with disposable HDPE pipettes in which the actual volume drawn for testing will vary greatly across a wide range of viscosities. This variation in volume can lead to measurement errors as high as 10 to 20 percent – increasing as the sample viscosity increases.

Conclusions

Bench-top semi-automated viscometers can offer a sufficiently accurate measurement for most field operations. These devices often follow the same principles and mimic some of the operation of a typical laboratory-grade viscometer while eliminating much of the complexity and operator interaction which would require a highly-trained laboratory technician. However, care must be taken to both understand and mitigate any sources of measurement error. Otherwise errant decisions might be taken on the sample based on an inaccurate viscosity measurement.

The operational faults discussed above have varying degrees of influence on measurement error. These faults can be considered additive. For example, one may have alignment, temperature, and contamination faults simultaneously which will cumulatively add to the

viscosity measurement error. When viscosity measurement precision is critical, care must be taken to control all three operational faults discussed in this paper.

<u>If accurate measurement precision is desired, the viscometer system needs to:</u>

- Provide temperature control of the sample which is better than +/- 0.1°C
- Not be operated at a severe angle (> 10%) with respect to vertical front-to-back
- Not be operated at any angle off vertical side-to-side when using the Q3000
- Be cleaned and the capillary properly inspected for contaminates before use – especially critical on the Q3000 where a wiping cloth is used to clean the capillary
- Utilize an accurate device for charging the sample volume into the viscometer
- Have the calibration periodically verified with a certified viscosity reference standard