Calibration of ViSmart® Viscosity Sensors for Printing Inks

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Introduction

This application note will review a simple calibration process that will provide accurate translation of the viscosity sensor AV readings into units of cup-seconds for a particular type of printing ink. The method only requires two measurements at the time of calibration and will give accurate translation of sensor AV into units of cup seconds for temperatures near the original calibration temperature. As the average temperature of the printing ink changes along with the seasons (i.e. going from winter to summer), the accuracy of the translated AV to cup-seconds will degrade. A third measurement under these new ambient conditions is all that is required to calculate a temperature compensation factor which ensures accurate cup-seconds translations regardless of the printing ink temperature.

The Calibration Procedure

Figure 1 below illustrates the calibration process for a sensor and a particular printing ink. The first set of sensor and cup measurements is obtained with the printing ink slightly thicker than the optimal viscosity. A target value of cup viscosity would be 10 to 15% greater in viscosity than the ideal printing ink viscosity. The second set of measurements is obtained at the optimal printing ink viscosity. The assumption is that the calibration temperature, T_{cal}, does not change considerably across the two sets of measurements. The calculation of the calibration coefficients, M and B, are then accomplished using the Equations 1 and 2 as shown in Step 3 of Figure 1 below.

Sensor Calibration Process

Step1: Obtain measurements (higher viscosity ink). (T_{cal}, AV_1, cup_1)

Step2: Obtain measurements (Optimal viscosity ink). (T_{cal}, AV_2, cup_2)

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Step3: Calculate the calibration coefficients that will translate sensor AV into cup seconds for temperatures near the calibration temperature, T_{cal}.

$$M = (cup_2 - cup_1) / (AV_2 - AV_1) \quad \text{Eq.1}$$

$$B = cup_1 - M * AV_1 \quad \text{E.2a}$$

or

$$B = cup_2 - M * AV_2 \quad \text{E.2b}$$

Figure 1. The calibration process flow diagram.

Once the calibration coefficients are calculated, measurements of AV can be translated into cup-seconds for the printing ink using Equation 3.

$$cup_{cal} = M * AV + B \, , \quad \text{Eq.3}$$

where M and B are calibration constants that relate the sensor viscosity (AV) to the viscosity cup value (cup_{cal}) in units of cup-seconds for temperatures near the original calibration temperature (T_{cal}). As long as the temperature remains close to the original calibration temperature, T_{cal}, then the translation of sensor AV into units of cup seconds for a particular printing ink will be accurate. A target temperature deviation range to work within would be +/- 2°C away from the original calibration temperature.

A Secondary Calibration Procedure to Compensate for Temperature Effects

As the seasons change (i.e. going from winter to summer), it is expected that the average temperature of the printing ink may change. As the temperature of the ink drifts further away from the original calibration temperature, the error in the AV to cup translation will be greater. Figure 2 below illustrates a temperature compensation process that consists of one additional set of measurements (any concentration in the vicinity of the prior calibration points). This allows the calculation of a temperature compensation coefficient that will restore the accuracy of the original calibration for all temperatures. A PLC can be programmed to detect when the temperature of the ink has drifted beyond +/- 2°C and alert the printing technician to take and enter a third cup measurement through a graphical interface. The calculation of the temperature compensation coefficient is then accomplished using Equations 3 and 4 in Step 2 of Figure 2.

Temperature Compensation Calibration Process

Step1: If the temperature of the ink exceeds +/-2°C from the original calibration temperature, obtain a third and final set of measurements. (T_3, AV_3, cup_3)

↓

Step2: Calculate a temperature compensation coefficient, K_t, that will allow us to compensate for temperature effects.

$$cup_{cal} = M * AV_3 + B \qquad \text{Eq.3}$$

$$K_t = \frac{\left(1 - \frac{cup_3}{cup_{cal}}\right)}{(T_3 - T_{cal})} \qquad \text{Eq.4}$$

Figure 2.The secondary calibration process to compensate for temperature effects.

Once the temperature compensation coefficient has been calculated, the sensor is fully defined for the printing ink and a wide range of temperatures. The final temperature compensated viscosity is calculated using Equation 5 below.

$$cup = (M * AV + B) * [1 - K_t (T - T_{cal})] , \qquad \text{Eq.5}$$

where M and B are the calibration constants that relate the sensor viscosity (AV) to the viscosity cup value (cup) in units of cup-seconds, K_t is the temperature compensation coefficient, T_{cal} is the original calibration temperature and T is the current temperature of the printing ink.

Example Calibration

The calibration data for two Flint MV White ink solutions is listed in Table 1. The first, higher viscosity solution is 20% Ethanol by volume and the second lower viscosity solution is 25% Ethanol by volume and is considered the optimal printing ink solution for this example. Calculation of the calibration and temperature compensation coefficients is shown below.

Table 1. Flint MV White Ink Calibration Data for a viscosity sensor at a calibration temperature of 16.35°C

Sensor Calibration Data (16.35°C)			
% Ethanol	Temp (°C)	Sensor AV	EZ Zahn#2 (cup-sec)
20.00	16.30	12.75	25.75
25.00	16.40	10.91	23.61

Calibration of a Viscosity Sensor at Tcal ~ 16.35°C

Calibration Step 1: Obtain measurements (higher viscosity ink).

$(T_{cal}, AV_1, cup_1) = \mathbf{(16.35, 12.75, 25.75)}$

Calibration Step 2: Obtain measurements (lower viscosity ink).

$(T_{cal}, AV_2, cup_2) = \mathbf{(16.35, 10.91, 23.61)}$

Calibration Step 3: Use equations 1 and 2 to calculate the calibration coefficients at a calibration temperature of 16.35°C.

$\mathbf{M} = (cup_2 - cup_1) / (AV_2 - AV_1) = (23.61 - 25.75) / (10.91 - 12.75) = \mathbf{1.16}$

$\mathbf{B} = cup_1 - M * AV_1 = 25.75 - 1.16 * 12.75 = \mathbf{10.96}$

or

$\mathbf{B} = cup_2 - M * AV_2 = 23.61 - 1.16 * 10.91 = \mathbf{10.95}$

For this viscosity sensor in Flint MV White ink at temperatures near the calibration temperature, the following equation can be used to translate sensor acoustic viscosity into units of cup-seconds for an EZ Zahn#2 viscosity cup. The accuracy will be good as long as the temperature does not exceed +/- 2°C from the original calibration temperature.

Sensor (T_{cal} = 16.35°C): $\mathbf{cup_{cal} = 1.16 * AV + 10.96}$

Compensation of the Viscosity Sensor for Temperature Effects

Compensation Step 1: When the temperature of the ink exceeds +/- 2°C from the original calibration temperature, obtain a third measurement.

$(T_3, AV_3, cup_3) = \mathbf{(20.10, 11.40, 24.62)}$

Compensation Step 2: Use equations 3 and 4 to calculate a temperature compensation coefficient, K_t, that will allow us to compensate for temperature effects.

$\mathbf{cup_{cal}} = M * AV_3 + B = 1.16 * 11.40 + 10.96 = \mathbf{24.18}$

$\mathbf{K_t} = (1 - cup_3/cup_{cal}) / (T_3 - T_{cal}) = (1 - 24.62/24.18) / (20.10 - 16.35) = \mathbf{-0.00485}$

Plugging the calibration and compensation coefficients into equation 5 results in the following relationship:

$$\mathbf{cup = (1.16 * AV + 10.96) * [1 + 0.00485 * (T - 16.35)]}$$

where the sensor response will be compensated for temperature and will be accurate for ink concentrations near the optimal ink solution concentration.

Summary

Temperature and sensor viscosity measurements are listed in columns 2 and 3 of Table 2 below for Flint MV White ink across a range of ink temperatures. Using the non-compensated and temperature compensated equations in the example above, the other columns of the data show the actual cup measurement, the calculated cup value without temperature compensation and the calculated cup value with temperature compensation. The corresponding accuracies are also shown and demonstrate excellent agreement with the actual cup viscosity measurements.

Table 2. Flint MV White Ink Sensor Measurements and Cup-Second Calculations

Actual Measurements				Uncompensated		Temperature Compensated	
% Ethanol	T (°C)	AV	EZ Zahn#2 (cup-sec)	cupcal (cup-sec)	% cup-sec Error	cup (cup-sec)	%Cup-Sec Error
20.00	16.30	12.75	25.75	25.75	0.00%	25.74	-0.02%
25.00	16.40	10.91	23.61	23.62	0.02%	23.62	0.05%
20.00	18.20	12.05	25.19	24.94	-1.00%	25.16	-0.11%
25.00	18.20	10.29	23.20	22.90	-1.31%	23.10	-0.42%
20.00	20.10	11.40	24.62	24.18	-1.77%	24.62	0.02%
25.00	20.20	9.73	22.75	22.25	-2.21%	22.66	-0.39%
20.00	22.10	10.80	24.02	23.49	-2.21%	24.14	0.51%
25.00	22.10	9.20	22.33	21.63	-3.13%	22.24	-0.42%

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About The Author

Ray Haskell has over 16 years of experience developing sensors and precision frequency control components. He is currently the Director of Engineering and Marketing for fluid sensor products at Vectron International. He has developed numerous sensor and frequency control technologies that have led to new and innovative products. More recently his focus has been on the development of bulk acoustic wave viscosity sensors for printing ink and lubricant applications and the practical implementation of this technology through the use of novel in-situ calibration algorithms. Prior to joining Vectron, Ray was a Senior R&D Engineer at Sensor Research and Development Corp. where he developed acoustic wave fluid and gas sensors and also developed high temperature semi-conducting metal oxide sensing transducers. Ray holds a M.S. in Electrical Engineering from the University of Maine (Orono) where he worked in the area of acoustic wave and solid state sensors. Ray has eleven patents and fifteen publications in the sensor and frequency control areas.